The Effectiveness of Groups Recognizing Patterns

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An experiment was conducted in which groups made resource allocation decisions while physically dispersed and supported with a shared virtual work surface (What You See Is What I See - WYSIWIS). The task required groups to recognize patterns of information and collaborate to allocate their resources appropriately. The experimental treatment involved the use of a tool specifically designed to minimize the cognitive effort required to recognize and share patterns among group members. Dependent measures included outcome quality, time-to-decision, consensus of pattern recognition, and the number of resource allocation moves required to reach consensus. All groups received significant financial rewards in direct proportion to their outcome quality. Groups supported with the pattern-sharing tool had significantly higher outcome quality and significantly less resource movements. These results extend the theory of Recognition-Primed Decision-Making by applying it to groups.

Keywords: Group Support Systems, Collaboration, Shared Cognition

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1.0 INTRODUCTION

Technological advances have led to large increases in the quantity and speed with which information is exchanged. Associated with these advances, the pace of business decision-making has also increased significantly in recent years. Decision making in such dynamic, continuously changing environments is called "naturalistic" decision-making; high stakes, time-pressure, and uncertainty characterize these situations. Researchers have found that in naturalistic domains, individual experts make almost 90% of their decisions by "feature matching" between the current situation and one from prior experience (Kaempf, Klein, and Wolf, 1996).

Humans have limited cognitive capacities for perception, memory and attention (Baddely, 1992; Baddely, 1998). Dynamic decision environments are especially taxing to our limited cognitive resources. Decision Support tools have been developed to support individual cognition in naturalistic domains (Morrison, Kelly, Moore, and Hutchins, 2000) and these tools are successful because they support specific cognitive strategies, such as "feature matching". They mitigate the effects of stress on short-term memory and attention management. The successful application of cognitive science to decision support technology makes it possible to consider extending these advantages to other decision domains.

In particular, teams rather than individuals make many decisions in naturalistic domains (Keltner, 1989) and thus, considerable effort has been devoted to the development of groupware to support these domains. Pendergast and Hayne (1999) have characterized groupware as software supporting group interactions, of which there are many different types. They categorize groupware by size, frequency of occurrence, composition, motivation and decision process, technology, dispersion and synchronicity. Furthermore, they suggest that a complete groupware infrastructure has four dimensions: communication (pushing or pulling information), collaboration (shared information leading to shared understanding), coordination, and control (management of conflict).

While there is a large literature on groupware (discussed below), we are not aware of any groupware that is specifically designed to optimize the utilization of human *cognitive* resources in dynamic situations; the systems address *behavioral* issues associated with human interaction. So, how can we apply theories of individual cognition to the design of collaboration and decision support tools for groups? In this article we propose a theory of group cognition for naturalistic decision domains. From this theory, we derived a collaboration and decision support tool for group-level feature matching (sometimes also called situation assessment or pattern matching). Our research question is *do groups engage in pattern recognition and response selection as has been observed in individuals?*

In the next section we describe the theories of individual cognition relevant to naturalistic decision domains. We explain our theory of group cognition, and describe the derivation of a team-based pattern-recognition tool. In section 3, we describe an experiment to validate our theory. Section 4 presents the results of that experiment, and discusses the implications. In section 5, we list our conclusions and suggestions for follow-on research.

2.0 PRIOR RESEARCH

Most products in our environment are traceable to group activity rather than individual activity (Thompson and Fine, 1999). Groups can accomplish larger and more complex tasks than individuals. As the size of a project increases, so typically does the need for some form of supervisory activity. In general, we view these supervisory activities as not directly contributing to a desired outcome, but rather they facilitate the activities that contribute directly to an outcome. An efficient group would devote a large amount of resource to activities that directly contribute to the desired outcome and a relatively small amount of resources to facilitating activities. There are many factors affecting group effectiveness and are categorized into process losses and process gains (for a review see Jessup and Valacich, 1993; Nunamaker, 1997).

In our context, the goal is to provide information management mechanisms that maximize process gains while minimizing process losses. While this simple model has an intuitive appeal, it begs the question, “how does one maximize gain or minimize loss?” The answers to these questions require the integration of at least three broad areas of study:

- The study of individual psychology, including cognitive abilities and limitations,
- The study of groups and social interactions, including communications and motivations, and
- The study of the role of artifacts as stimulating structures for human interactions.

A complete review of any one of these topics is beyond the scope of this paper, so we will limit our review to a subset of these topics that apply most directly to our research objectives.

To further reduce the scope of our inquiry, we make some assumptions concerning the nature of the groups we wish to study. For example we assume that the members of our groups are drawn from an established organizational culture and that they share a common body of knowledge with respect to the task domain. We assume that each group member understands their role in the group, and the roles of the other group members. We assume that the members are motivated to achieve the stated objectives of the group.

In the following sections we review literature that describes the characteristics of natural task domains and the limitations of individual cognition as it relates to those domains. We review theories of group-level cognition related to transactive memory, shared mental models, and distributed cognition. Finally, we review the literature on stimulating structures and computer mediated interaction in order to offer a prescription for the development of computer-based tools for supporting group work in natural domains.

2.1 Naturalistic Decision Making by Individuals

Klein (1993) used the term “naturalistic decision making” to refer to dynamic situations that are characterized by high stakes, time pressure, and uncertainty. These situations are dynamic in the sense that they involve a series of judgments and actions. Each action may result in a change to the situation. In a typical situation, a decision maker must observe the results of his/her actions and adjust subsequent actions based on this feedback. Usually the decision maker operates with incomplete information which creates a degree of uncertainty with respect to their assessments of the situations and the effects of their actions. Often, the situation is changing rapidly due to influences beyond the control of the decision maker; this may create the feeling of time pressure.

Klein (1993) developed the theory of Recognition-Primed Decision Making (RPD) to describe how individual experts make decisions in these naturalistic environments. Klein’s theory is that experts make incremental decisions based on recognizing patterns in a developing situation. According to RPD, tactical decision makers recognize the current situation in so far as it is similar to some recalled and similar situation stored in their memory. This situation awareness, and its associated plan of action, is retrieved from memory for use in the current situation. Kaempf, Klein, and Wolf (1996) found that experts make almost 90% of their decisions by “feature matching" between the current situation and one from prior experience. Similar findings have been demonstrated in the domain of chess (Chase and Simon, 1973; Gobet, 1997; Gobet and Simon 1998; Gobet and Simon, 2000).

Experts have a large amount of prior experience from which they can adapt known solutions. Nevertheless experts periodically encounter novel situations. In unfamiliar cases when the RPD process does not yield a "feature-match," decision-makers employ an "explanation-based reasoning" process (Pennington and Hastie, 1993). Here, decision-makers generate a "story" that accommodates some of the observed data, thereby providing a plausible interpretation of the situation. Based on this explanation, the decision maker develops an expectation of what might happen next in the story. By comparing their expectations with their observations as the situation develops, the decision maker can confirm or disconfirm the story. Decision makers take actions that they believe will influence their stories to have a desirable ending.

Based on these descriptions of expert decision processes in naturalistic domains, we begin to see how we might build computerized tools to support individual decision making. The tools should be designed to facilitate the detection of patterns in the environment, and to display and replay sequences of events as an aid to explanation-based reasoning. Without computer tools, pattern recognition and story-telling require considerable cognitive effort. To be effective, these tools must be designed with consideration of human cognitive limitations (Hoffman, Crandall and Shadbolt, 1998).

2.2 Individual Cognitive Limitations

Humans have limited cognitive capacities for memory, attention and perception (Norman and Bobrow, 1975). Miller (1956) described the limitations of short-term memory as "the magical number 7," suggesting that most people can remember about 7 things at any given moment. We also have difficulty dividing attention among several tasks, or attending to all the information provided by our senses (Broadbent, 1958; Treisman 1969). As a result, we often do not perceive most of the information that is available to us (Lavie, 1995).

Dynamic decision environments are especially taxing to our limited cognitive resources. Under time pressure people tend to focus their attention on immediate, highly structured, tasks while avoiding more important and complex tasks (Morrison, Kelly, Moore, and Hutchins, 2000). Limitations to short-term memory make it difficult recognize patterns because we can't remember all the features of a developing situation long enough to recognize an emerging pattern. Similarly, it is difficult to recognize slow-developing trends. The limitations of short-term memory are exacerbated by the stress of time pressure: it has been shown that stress causes the release of a cortical steroid that interferes with memory (de Quervain, Roozendaal, Nitsch, McGaugh, and Hock, 1998; Kirschbaum, Wolf and Hellhammer, 1996).

Recently, decision support tools have been developed to support individual cognition in naturalistic domains (Morrison, Kelly, Moore and Hutchins, 2000) and these tools are successful because they support specific cognitive strategies, such as "feature matching". They mitigate the effects of stress on short-term memory and attention management. The successful application of cognitive science to support for individual decision-makers is a cornerstone of our strategy for the support of groups. In the following section, we review theories of group-level cognition in search of similar leverage points for improving performance.

2.3 Collective Memory, Shared Mental Models and Shared Cognition

Ideally, groups should be less affected by the cognitive limitations of their members. Consider a team attempting to recall the names of all the US state capitals. Most likely there will be several capitals that every member knows. This is information that the group holds in common. One would also expect that the gaps in the members' knowledge would complement each other to some extent, so that the collective recollection of the group would be superior to the average individual recollection.

In order to achieve the benefits of collective recall, the individual group members will require a system for encoding, storing, retrieving, and communicating. This system has been called a transactive memory system (Wegner, 1987). This system includes the cognitive abilities of the individuals as well as meta-memory, that is, the beliefs that the members have about their memories. Thus, the members of a group have access to the collective memory by virtue of knowing which person remembers which information.

Under certain circumstances group memory has been shown to be superior to individual memory (Hinsz, 1990) and can lead to superior task performance (Moreland, 1999). More typically, however, the performance of groups rarely exceeds the performance of the group's best individual member (Hill, 1982). Ineffectiveness in transactive memory systems may be a result of inefficient sharing of information within groups. Research has shown that during collective recall, groups are more likely to exchange and discuss "common" information shared by all group members than information known by only one group member (Dennis, 1996; Wittenbaum and Stasser, 1996). Other factors that have been shown to affect information sharing in groups include the experience of the team members and the disconfirming nature of information (Kim, 1997; Stasser, Vaughan & Stewart, 2000; Stewart, 1998). The stress of time pressure in naturalistic situations may compound the problems with transactive memory systems because the cortisol released impairs the meta-memory of "who remembers what," leading to breakdowns in collective recall.

Of course, there is more to group cognition than collective memory. Cannon-Bowers, Salas, and Converse (1993) suggest that for teams to be effective, the members must have common cognitive representations of task requirements, procedures, and role responsibilities. Cannon-Bowers, et al. refer to this as a shared mental model. These shared mental models provide mutual expectations that allow the teams to coordinate their efforts and make predictions about the behaviors and needs of their teammates (Cooke, Salas, Cannon-Bowers, and Stout, 2000). A team's understanding of a complex and dynamic situation (team situation awareness) is influenced by the collective knowledge, skills, and attitudes of the team (Cooke, Stout, and Salas, 1997).

In the same way that transactive memory systems are dependent upon the existence of meta-memory, shared mental models require that group members maintain a meta-model of "who does what, when." However, meta-models are not universally effective and are vulnerable under the stress of time pressure. Thus, there is an opportunity to improve group performance through support of transactive memory systems and shared mental models. Hutchins' (1991, 1995) work on distributed cognition suggests one mechanism to accomplish this goal.

Group activity necessitates a division of labor, which in turn requires some distributed cognition to coordinate the activities of the participants (Thompson and Fine, 1999). For distributed cognition, Hutchins (1991) defines the unit of cognitive analysis as a distributed socio-technical system. The cognitive properties of this system are produced by an interaction between the structures internal to individuals and structures external to individuals. In particular, that portion of cognition that that governs the coordination of the elements of a task might be represented in the external environment, and be available for inspection. By making this representation "public", the group can share it. Hutchins (1995) describes how a group's use of a technical artifact can transform a complex computational task into a simple perceptual task. For example, a pilot team sets the airspeed "bug" on the desired airspeed so they can share perceptions of whether the aircraft is being flown at, above or below the target airspeed. This technical artifact, when used as a part of a distributed socio-technical system, is an example of the use of a stimulating structure.

2.4 Stimulating Structures

Grassé (1959) coined the term stigmergy, referring to a class of mechanisms that mediate animal-animal interactions. The concept has been used to explain the emergence, regulation, and control of collective activities of social insects (Susi and Ziemke, 2001). Social insects exhibit a coordination paradox: they seem to be cooperating in an organized way. However, when looking at any individual insect, they appear to be working independently as though they were not involved in any collective task. The explanation of the paradox provided by stigmergy is that the insects interact indirectly by placing stimulating structures in their environments. These stimulating structures can direct and trigger specific actions in other individuals (Theraulaz and Bonabeau, 1999).

As described earlier, effective team performance requires transactive memory systems and shared mental models. The cognitive effort required to maintain these meta-models may not always be available to teams operating in naturalistic situations. The distinguishing characteristic of stimulating structures is that they require very limited cognitive effort. Stimulating structures are artifacts placed in the external environment; their placement does not diminish the limited memory resources of the human members of the socio-technical system. Interpretation of stimulating structures is primarily a perceptual task; such tasks require less cognitive effort than reasoning or computational tasks. Thus, we suggest, the opportune application of stimulating structures may be the key to enabling transactive memory systems and shared mental models to function under dynamic conditions.

In the following section, we formulate our model of group decision making in naturalistic conditions, and provide prescriptions for the design of technical artifacts that provide cognitive support at both the individual and team level.

2.5 Model of Team Recognition Primed Decision Making

Our model of team decision-making in naturalistic environments is shown in Figure 1. Hutchins (1991) asserts that a distributed socio-technical system engages in two kinds of cognitive work:

the cognition that is the task, and the cognition that governs the coordination of the elements of the task. The portion of cognition that is the task is carried out internally to the individual members of the system. Because of this, we believe that our model of team decision-making in naturalistic environments can be adapted from Klein's (1993) model of individual experts.

We suggest that teams perform essentially the same steps as individual experts, with some additional executive functions. Similar to individual experts, we hypothesize that teams assess the situation and perform "feature-matching" tasks which trigger recall of similar situations from their collective memory. Next, teams select a response by adapting a strategy from their previous experience. Finally, teams execute their plan, and observe the results. The additional tasks required of teams involve synthesizing their assessments of the situation among members, communicating their expectations of what might happen in the near future, and (for teams with semi-autonomous members) their intentions for response. As mentioned earlier, these additional functions are dependent on effective transactive memory systems and robust shared mental models.

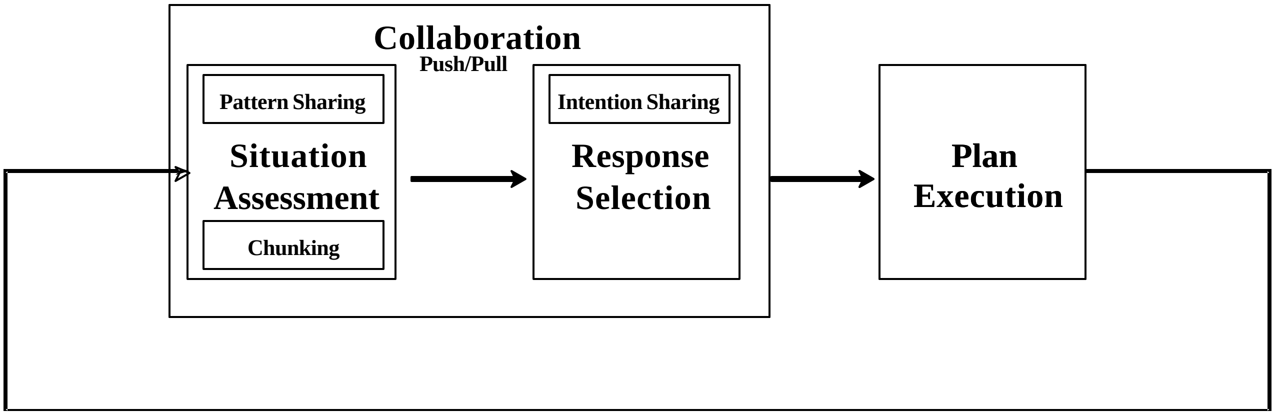


Figure 1: Team Recognition Primed Decision-Making

Kaempf, Klein, and Wolf (1996) found that individual experts spent most of their time scanning the environment and developing their situation assessments. Relatively little time was spent selecting and implementing responses. If the situation assessment task has the same relative importance for teams as for individuals, then the initial focus for team decision support should be directed towards the development of tools to support collective situation assessment. For individual members, these tools should be designed to reduce the cognitive effort required to perceive patterns, attend to the highest priority tasks, and remember the most important features of the task environment. For the group, these tools should facilitate sharing of assessments through placement of stimulating structures. Our theory suggests that teams will also derive some benefit from stimulating structures that facilitate sharing of expectations and intentions.

In the next section we review current research into groupware that might involve sharing stimulating structures.

2.6 Computer Mediated Interaction

To mitigate the process losses and gains mentioned above, much research has been conducted into software to support computer-mediated interaction (CMI) or groupware. This includes areas of research into group decision support systems (GDSS) and computer-supported cooperative work (CSCW). GDSS enforces rules of meeting protocol and structure in an "interactive computer-based system that facilitates the solution of unstructured problems by a set of decision-makers working together as a group" (DeSanctis and Gallupe, 1987). Existing GDSS tools facilitate both small (3-6 members) and large (7-30) groups through the various stages of the decision-making process (Gallup et al., 1992; Valacich, Dennis, and Nunamaker, 1992).

On the other hand, CSCW is defined as "the study and theory of how people work together, and how the computer and related technologies affect group behavior" (Rein and Ellis, 1990). CSCW implementers build "computer-based systems that support two or more users engaged in a common task (or goal) and that provide an interface to a shared environment'" (Ellis, Gibbs and Rein, 1991; Stefik et al, 1987). These systems usually facilitate communication between members of a small group and provide task-specific tools. The software rarely regulates the actual meeting process; the designers expect that normal social protocols between participants will suffice. These systems have branched into Collaborative Virtual Environments (Singhal and Zyda, 1999) with *relaxed* WYSIWIS (What You See Is What I See), *shared views/awareness* and *telepointers* (Greenberg, Hayne and Roy, 1995).

Groupware can influence the structure of group interaction through enforced procedures embedded in the software; enforced structuring of group interaction appears to yield positive results when there is a good task-structure fit (Dennis, et al., 1999). For example, the possibility for groups to work anonymously and in parallel may result in a reduction of production blocking. Interestingly, these interactions may not be as anonymous as previously thought (Hayne and Rice, 1999; Hayne, Pollard and Rice, in press). Sometimes, groups have better results as both group size and task complexity increase (Benbasat and Lim, 1993; Hedlund, Ilgen and Hollenbeck, 1998). And, when participants have a need to refer to artifacts involved in the collaborative task, group awareness, shared views and telepointers are useful mechanisms (Benford and Greenhalgh, 1995; Hayne and Pendergast, 1995; Lai and Malone, 1988; Valin, Fancu, Trefftz and Marsic, 2001). This notwithstanding, it appears that both face-to-face and computer mediated groups make riskier decisions and exhibit greater choice shift than do individuals (Cox and Hayne, 2002; Weisband, 1992). The risk-shift phenomenon seems to be related to social influence (Myers, 1982; El-Shinnawy and Vinze, 1997). Under time pressure, groupware may affect this risky shift (Smith and Hayne, 1997). Furthermore, it has been suggested that the low bandwidth connections between groupware users are unable to provide mechanisms for coordinating actions, creating agreement, confidence and trust within groups (Grudin, 1994; Kraut, et al., 1992; McGrath and Hollingshead, 1994). Thus, many systems and subsequent studies have had mixed results affecting group interaction (for a review see Jessup and Valacich, 1993; Mcleod, 1992; Nunamaker, 1997; Pinsonneault and Kraemer, 1990).

For our research, we are concerned with enhancing a small group's real-time interaction where there is no time or ability to have a face-to-face meeting, no facilitation available, nor the bandwidth to support video conferences, i.e. a naturalistic decision environment. We suggest that the mixed results are due to a focus on behavioral issues, tasks and technology, rather than a solid grounding in basic cognitive principles. We will focus on enhancing human cognitive limitations in our prescriptions for group decision support in naturalistic conditions.

2.7 Prescriptions for Group-level Cognitive Support

We believe that the cognitive effort required to perform group tasks can be reduced through placement of stimulating structures in the external environment of a socio-technical system. This reduction of effort is shown by the link from Stimulating Structures, through Task Difficulty and ending in Performance (see Figure 2).

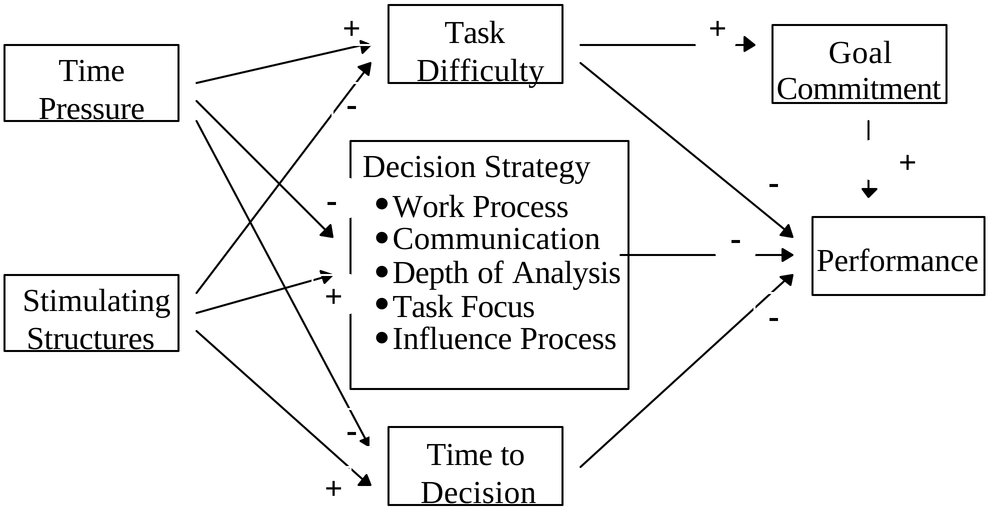


Figure 2: A Model of Decision Making Under Time Pressure

(cited from Smith and Hayne, 1997)

We hypothesize that the guiding principles for the design of these stimulating structures are as follows:

- The stimulating structures should be pushed to the external environment rather than directly to individual group members. The stimulating structures should be pulled from the external environment rather than directly from group members. This principle follows from the work of McFarlane (2002) in which he found that "negotiated interruption" yielded the best results for coordinating actions. As Hutchins (1991) points out, every distributed task requires two types of cognition: cognition that is the task, and the cognition that governs the coordination of the elements of the task. Thus group work will necessarily involve frequent interruptions as group members switch their attention between task-cognition and coordination-cognition. Pushing and pulling the stimulating structures to/from the external environment implements a negotiated interruption strategy.
- The stimulating structures should require minimal effort to place into and retrieve from the external environment. Ideally they should transform complex cognitive tasks into simple perceptual tasks.

- The most important stimulating structures for group work in naturalistic situations are related to situation assessment. The structures should convey information regarding "feature-matching" from the current situation with a previously recalled situation.
- Our theory suggests that teams will also derive some benefit from stimulating structures that facilitate sharing of expectations and intentions. In this case, the stimulating structures might indicate the nature or location of an expected event, or the type of intended response.

In order to isolate the effects of individual-level support from group-level support, we apply only our group-level stimulating structures in our study. Furthermore, we have limited the stimulating structures to situation assessment phase of a task (pattern recognition and sharing), to eliminate potential confounds with the effects of other stimulating structures. In particular, the group will benefit from a single stimulating structure that:

1. implements a negotiated interruption strategy, and
2. requires a minimal effort to place into the environment, and
3. requires only a perceptual effort for interpretation, and
4. applies to the situation assessment phase of decision making.

Thus, our hypotheses are:

> ***Hypothesis 1.*** *The average outcome quality of the groups supported with a stimulating structure for sharing patterns will be greater than the average decision quality of the groups without.*
>
> ***Hypothesis 2.*** *Within groups supported with a stimulating structure for sharing patterns, the average outcome quality will be greater for groups whose individual members share similar assessments of the patterns than for groups whose members disagree about the patterns.*

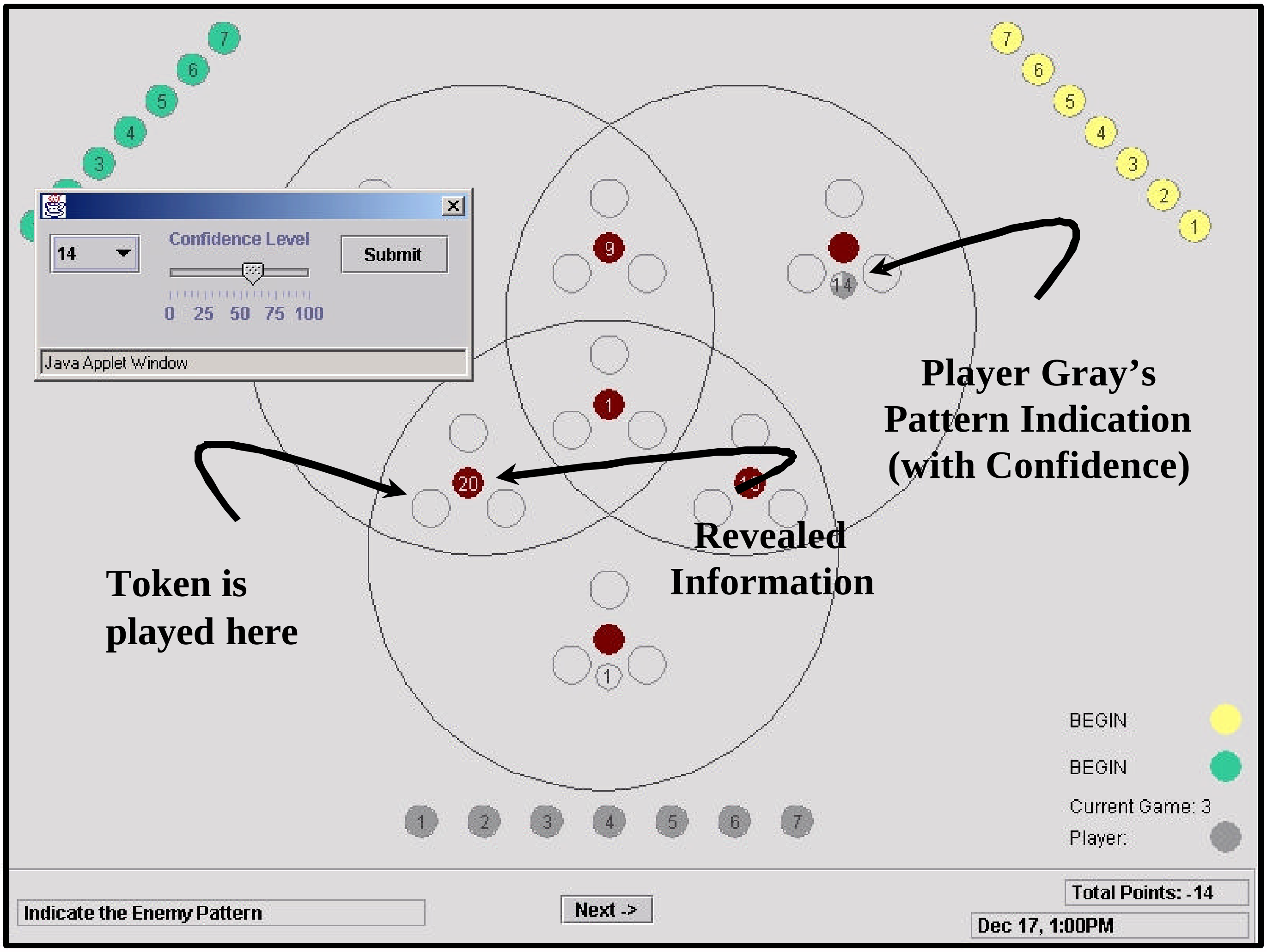
To test our hypotheses, we have created a cooperative decision task that involves elements of pattern recognition and response selection. We have built a shared visual surface and a "thin" tool for pattern sharing. Our decision task, tool and research design are described in the following section.

3.0 METHOD

3.1 The Decision Task

In order to validate our model, we created a collaborative game consisting of a java applet running in client browsers incorporating real-time gesturing (tele-pointers) and a pattern-sharing tool (http://www.speedofheat.com/hayne/onr).

The game is an extension of a two-player game developed by McGunnigle, Hughes, and Lucas (2000). In our game, groups of three participants play a game against nature in a series of independent decision scenarios. In each scenario, players need to allocate their resources to match a partially-revealed pattern. An image of the game display is shown in Figure 3.



Player Gray's Pattern Indication (with Confidence)

Revealed Information

Token is played here

Confidence Level: 14

Java Applet Window

Current Game: 3

Player:

Indicate the Enemy Pattern

Total Points: -14

Dec 17, 1:00PM

Figure 3: Multiplayer Collaborative Game

The game involves the collaborative playing of game tokens. The tokens are numbered and represent resources that each group member may allocate independently (by clicking on the token and dragging it to one of the token-sized open circles). Specifically, each team member was supplied with 7 tokens, with resource values from 1 to 7. There are seven regions, defined by the areas created by three overlapping circles. In each region, a maximum of three tokens can be played. The dependent variable is the count of the number of regions that the players "win." Winning a region is defined by adding the value of each token played within that region, and comparing the resulting sum to the value of the pattern in that region (the value in the red circle). If the sum of the players' tokens is equal or greater than the value of the pattern in that region, then the players "win" that region. For example, when a team is faced with a 20 in the red circle, the team must play at least two 7's and a 6 token (7+7+6 = 20) if they want to win that sector. On each trial, only part of the pattern was revealed; the challenge for the participants was to play tokens in the appropriate regions to match both the revealed and the *unrevealed* pattern values.

The objective of the game was for the team to win as many sectors as possible. Each of the 3 patterns was constructed in a way that the participants could win all 7 sectors if they placed their tokens appropriately. Each pattern contained a 20 and a 19; for a team to achieve a perfect score on any trial, each player would have to allocate their 6's and 7's precisely. In other words, to match a pattern value of 20 requires the play of two 7 tokens and a 6 token and then to match the 19 requires the play of two 6's and a 7. Only by playing cooperatively and in collaboration could the teams achieve a match against both the 20 and the 19 in every pattern.

Thus, the scores could range from 0 to 7 on each trial. Scores less than 4 required a deliberate error, such as the players neglecting to place their tokens, because each pattern contained at least three 1's. In pilot testing, debriefed teams' suggested that the task of recognizing one of three partially revealed patterns was moderately difficult, but were stil able to finish within the allotted time.

Patterns were randomly presented in any of three rotational orientations (spun 120º). Prior to data collection, participants were provided a sheet of paper containing a drawing of each of the 3 patterns, and allowed to play six practice trials while viewing the patterns. After the practice trials were completed, the participants surrendered the pattern drawings.

Each data collection session involved participants playing multiple independent trials, with the various patterns being partially revealed to the participants. For instance, only the 20, 19, 9 and one of the 1s is revealed during the trial shown in Figure 3.

3.2 Independent Measures

The game is played on a computerized board. Players have a shared virtual surface upon which to work. In the baseline treatment (BASE), the game was played without any support for pattern sharing. In the Pattern Sharing (PS) treatment, each player used a tool to indicate and share with their team members the pattern they thought they were playing against, and the level of confidence in their pattern assessment (the dialog box in Figure 3). All team members could see all other team members' pattern indications in real-time. In both treatments, each member of the group placed their tokens independently and their team members could see where they placed their tokens in real-time. All team members must indicate they are finished a trial before the team can progress to the next trial. There were 24 trials.

For each data-collection session, a predefined set of 3 patterns were chosen (see Figure 4). For each of these patterns, we covered certain sectors, to create a set of partially revealed patterns. These partially revealed patterns were categorized into one of three types: definitive (D), luck (L), and strategy (S). A *definitive* pattern was one that each participant should be able to identify completely. A *luck* pattern was one in which the amount of information revealed made the pattern equivocal. A *strategy* pattern was one in which the amount of information revealed was such that the participants could choose a strategy for minimizing the sectors lost, even though they would not know definitively which pattern was presented. These partially revealed patterns were presented to the participants in random order (all teams saw the same random order). There were 6 definitive, 5 luck, and 13 strategy patterns used in each block of 24 trials. On every trial, team members saw the same partial pattern.

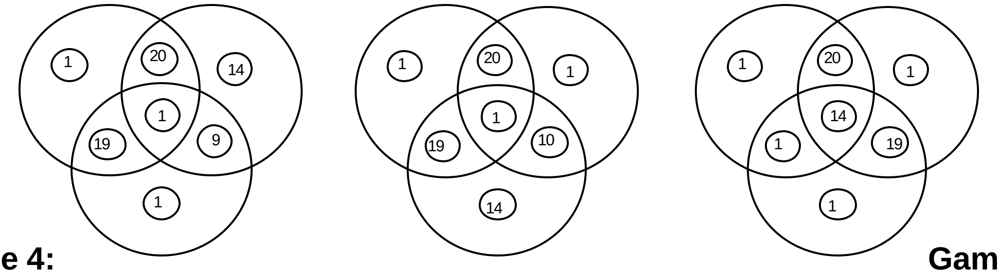


Figure 4: **Game Patterns**

3.3 Dependent Measures

The following data were captured: 1) patterns indicated along with confidence values; 2) all player moves; 3) sectors won/lost by the team during a trial; 4) timing associated with the above events; and 5) player demographics.

3.4 Subjects

For this study, we used 48 3-person teams of undergraduate students enrolled in a junior level course at a state university in the western United States. The sessions took place in a large computer lab (40 workstations). Participant seating locations were assigned so as to physically separate group members as much as possible. A maximum of 2 hours were available for each data collection session. Except for one, all teams finished well within the allotted time.

3.5 Incentives

In order to provide additional realism, subjects were externally motivated to take these experiments seriously and to behave "as if" they were making real business decisions (Cox, Roberson and Smith, 1982). This was accomplished by instituting a salient monetary payoff function directly related to the groups' decision quality, as measured by the number of sectors won in every trial:

individual quality payoff per trial (US$) = (*correct sectors – 5)* * $0.50

Subjects were informed of this function and told that money would be paid to their group in cash at the end of the experiment (after 24 trials). The incentive money was displayed ($1500) in a large pile at the front of the lab to encourage them to believe they would indeed be paid. Subjects were also paid $5 to show up on time for the session. Individual participants typically earned $15-20 for the session.

3.6 Experimental Procedures

All subjects in the first experiment received training in the use of the system immediately prior to the game. During the practice sessions the subjects were shown the results of their decisions, and informed of the payoff that they would have received if the practice session had been real. The subjects were given the opportunity to ask questions about experimental procedures. At the completion of the last trial, the subjects were debriefed, paid, and dismissed.

4.0 RESULTS

4.1 Outcomes

The results for outcome quality vs. pattern type are shown in Figure 5. Outcome quality is reported as a normalized score: the ratio of the number of sectors in which the teams scored a "win" divided by the expected value for the partially revealed pattern. The expected value for definitive patterns was 7 out of 7 regions. The expected value of the luck scenarios reflected the probability of guessing correctly when no useful information was revealed. In the remaining scenarios it was possible to play strategically so as to guarantee a score of 5 or 6 regions, while eliminating the chance to score 7 regions. In these scenarios, the expected value was deemed to be the minimum score achievable through application of strategy. Two treatments are shown in Figure 5: Baseline (BASE) and Pattern Sharing (PS). BASE refers to the treatment in which no tool was provided for sharing patterns among team members. The pattern-sharing tool was provided for the PS treatment.

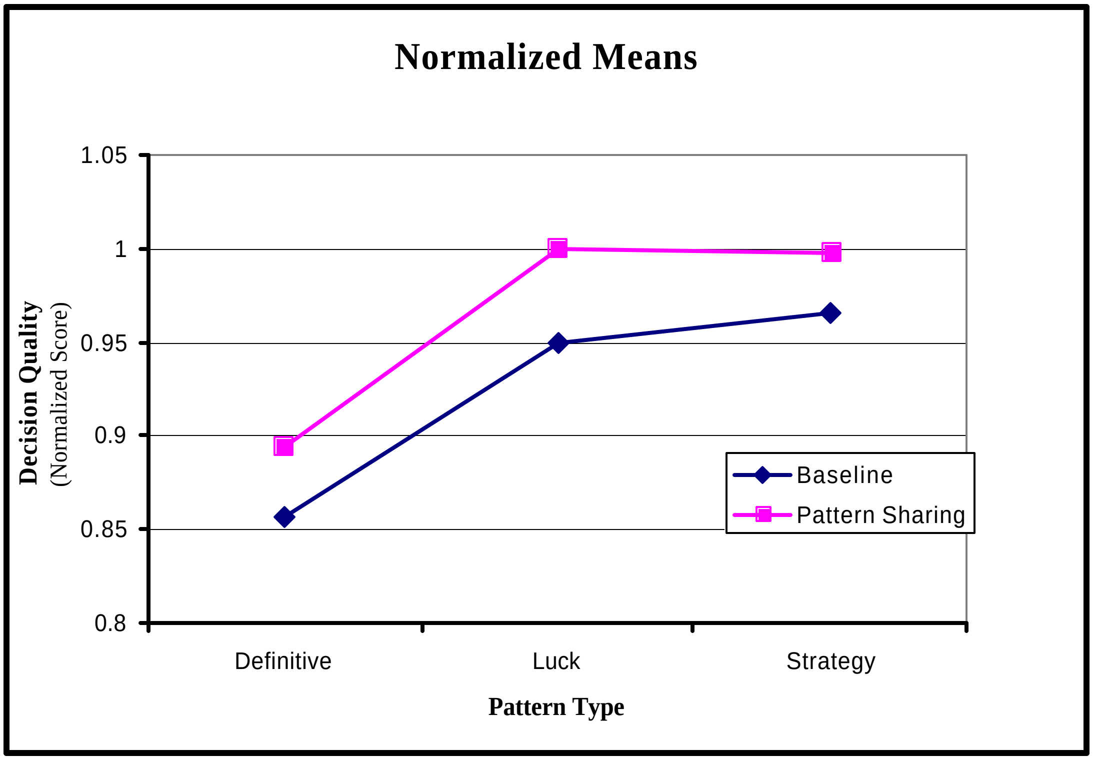


Figure 5. Outcome Quality

Hypothesis 1 was supported. For each type of pattern, the participants using the pattern-sharing tool significantly outperformed those not using the tool (F= 16.27, $p < 0.001$). In addition, we found that the types of patterns had a significant impact on performance ($F = 49.76$, $p < 0.001$). Teams performed at the expected value for the Luck and Strategy categories when using the PS tool. The Pattern-Sharing tool was designed to improve performance at the pattern-recognition task. Specifically, the PS tool was intended to promote the sharing of expectations concerning the unrevealed values during each trial. We believe that the PS tool facilitated a collective recall of partially recognized or partially remembered patterns among team members. This advantage was achieved by reducing the cognitive effort associated with transactive memory.

4.2 Decision Processes

Collective recall can be confounded by social influence: if most of the team members have accurately recognized the pattern, then there should be a positive outcome. However, if most team members have incorrectly identified the pattern, then the social influence of "majority rule" might lead to a poor outcome.

Although the PS tool was associated improved overall performance, Hypothesis 2 predicts that pattern-sharing tool would improve performance among those groups having a majority of members who accurately identified the patterns. Hypothesis 2 was supported. We categorized the teams with respect to the number of team members who had accurately indicated the patterns to their teammates (0, 1, 2, or 3). For this analysis, we included only those teams in which all three members had indicated at least one pattern element. We performed a Chi-Square analysis by categorizing the trials by accuracy of pattern recognition and the quality of the eventual outcome. An accurate indication was one in which all of the pattern elements indicated by a team member were correct. For example, in Table 1, the column counts labeled "All 3" refer to those trials in which all team members indicated accurate patterns to each other. The "High Outcome" row counts reflect all the trials where the eventual outcome equaled or exceeded the expected value for the specific partially-revealed pattern. The analysis in Table 1 suggests that the effects of social influence were significant ($?^2 = 40.86$, $p << 0.001$). The proportion of teams with good outcomes was much greater than expected when at least 2 out of 3 team members correctly identified the pattern (compare 3 bad outcomes vs. 19.6 expected if social influence weren't important; 44 good outcomes vs. 27.4 expected). Teams in which only one member correctly identified the pattern achieved almost exactly the expected outcome (19 vs. 19.2; 27 vs. 26.8). It seems that the "expertise" of a single team member is precisely balanced by the social influence exerted by the inaccurate beliefs of the remaining members. Finally, when all three members had incorrectly indicated the pattern, the outcomes were much worse than would be expected (101 bad outcomes vs. 78.5 expected; 87 good outcomes vs. 109.5 expected).

Frequency Count (trials)				
	Number of Team Members Indicating Accurate Pattern			
Performance	**0**	**1**	**2**	**All 3**
Low Outcome	101	19	4	3
High Outcome	87	27	19	44
Expected Low	78.5	19.2	9.6	19.6
Expected High	109.5	26.8	13.4	27.4

Table 1: Analysis of Accuracy vs. Outcome

In the pattern sharing treatment, PS tool was not used by all team members on every trial. Furthermore, most participants used the PS tool to identify only the distinctive features of an unrevealed pattern. A rival explanation for the mechanism by which the PS tool creates its effect is that some team members might have used the PS tool more frequently than others, and thereby produced a disproportionate influence on their teammates. This influence might be manifested by, for example, a single team member "flooding" his teammates with predictions of a pattern. The two interesting cases involve teams with 2 *vs.* 1 splits in pattern expectations. For teams where the minority member flooded his teammates with inaccurate pattern predictions, we might expect to see outcomes worse than average. Similarly, for teams in which the minority member floods his teammates with accurate pattern predictions, then we might expect to see better outcomes than average. To test this rival hypothesis we again divided the teams by virtue of the accuracy of their recognition of the patterns and the quality of their eventual outcomes, using only those trials having a 2 *vs.* 1 split in opinion. In each case, we counted the number of pattern elements predicted by majority and minority members of the teams. The analysis suggests that the quantity of shared pattern elements by minority members did not affect the outcomes ($?^2 = 1.32$, *ns*).

Klein's theory of Recognition Primed Decision-Making predicts that individuals will expend more time and effort on developing their situation awareness than on selecting a response. We hypothesized groups would make similar divisions in their collective efforts. Therefore we expected to observe that our groups using the PS tool should spend less time and effort moving their tokens than the control groups. We observed that the total time-to-decision was about 12.5%

longer for the teams using the PS tool (125.4 seconds per trial vs. 111.4, p <.01). Teams using the PS tool spent about 36.4% less time moving their tokens (70.9 seconds vs. 111.4, p << .01). We also counted the number of tokens moved by groups. Participants not using the PS tool made an average of 9.94 moves per game; those using the PS tool made only 8.38 moves per game (F = 102.2, p << .001). This difference is especially significant because each player has 7 tokens to play each game; so moves in excess of 7 represent "wasted effort." In percentage terms, the PS tool was associated with a 56% reduction in wasted effort.

5.0 CONCLUSIONS

Previous research has shown that individual experts use feature-matching to make decisions in naturalistic environments. In our study we have demonstrated that a tool designed to promote sharing of patterns among team members was associated with significant improvements in performance in a strategy game. The pattern-sharing tool improved the *collective* recognition of patterns by our teams. We believe that the improvements in collective pattern recognition were a direct result of reducing the cognitive effort involved with perception and memory during the Situation Assessment phase of our model in Figure 1. The reduction in cognitive effort was achieved through the use of a stimulating structure placed into the external environment of the distributed socio-technical system. We believe that our model can be applied to other settings characterized by high stakes, time pressure, and uncertainty. Our model should apply to other groups that have shared goals and either no direct supervision, or insufficient time for supervisors to micro-manage their actions.

6.0 FUTURE RESEARCH

In our study, we revealed the same partial pattern to each member of a team. Teams usually share some common information, but also typically have some specialized local information. This is problematic because prior research has shown that during collective recall, groups are more likely to exchange, discuss and focus on information shared by all group members than information known by only one group member (Wittenbaum and Stasser, 1996; Stasser, Vaughan, and Stewart, 2000). We believe that the PS tool should mitigate the problems associated with sub-optimal sharing of private information in pattern-recognition tasks. A follow-on study of this phenomenon is planned in which we will provide each team member with different (private) information concerning the patterns: some information will be common to the team, and some will be "local."

In naturalistic environments, decision makers are faced with dynamic situations in which the patterns are constantly changing. In our study, the patterns were static for the duration of a trial. We are in the process of developing a version of our strategy game in which the patterns change slowly during the course of a game trial. Once again, we believe that a pattern-sharing tool should reduce the cognitive loads on the team members, and promote improved performance.

Humans have limited cognitive resources for perception (e.g. of patterns), attention, and memory. The stimulating structure for pattern-sharing seemed to reduce the cognitive effort required for group members to divide their attention between coordination tasks and execution tasks. In our study we had only one execution task: the moving of game tokens. However, in naturalistic environments, there are often multiple simultaneous tasks that must be executed. In multi-tasking environments, stimulating structures that reduce the cognitive effort of coordination might be especially important. Thus, another possible extension of this research involves the extension of the task domain to include multiple execution tasks for each group member.

This research was conducted with undergraduate college students motivated to behave "as if" they were actors in a naturalistic setting. It would be useful to see if our model generalizes to field settings.

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