COORDINATED AWARENESS OF SITUATION BY TEAMS (CAST): MEASURING TEAM SITUATION AWARENESS OF A COMMUNICATION GLITCH

Jamie C. Gorman[1,3] Nancy J. Cooke[2,3] Harry K. Pederson[1,3] Olena O. Connor[1,3]

Janie A. DeJoode[4]

[1]New Mexico State University
Las Cruces, NM

[2]Arizona State University
Mesa, AZ

[3]Cognitive Engineering Research Institute
Mesa, AZ

[4]Intel Corporation
Chandler, AZ

A coordination-based measure of team situation awareness is presented and contrasted with knowledge-based measurement. The measure is applied to team awareness of a communication channel failure (glitch) during a simulated unmanned air vehicle reconnaissance experiment. Experimental results are reported, including the findings that not all team members should be identically aware of the glitch and that appropriate levels of coordination are an important precursor of team situation awareness. The results are discussed in terms of the application of coordination metrics to support the understanding of team situation awareness. The use of team coordination as a low-dimension variable of team functionality is scalable over a variety of team sizes and expertise distributions.

INTRODUCTION

"Situation awareness" (SA) was recognized originally in the aviation community as a phenomenon in which a pilot quickly and adaptively reacts to changes occurring within and outside the cockpit. This phenomenon was introduced into the psychological community as a cognitive construct involving the guidance of goal selection in a dynamic environment, based on a sequence of activated schemata, mental models, and situation models (Endsley, 2000). The roles of working memory, long-term memory, and long-term working memory in SA have accordingly been considered as important cognitive constructs underlying this phenomenon (Sohn & Doane, 2004). In this tradition, team situation awareness (TSA) has been viewed as an aspect of team cognition, by which a knowledge-heterogeneous team constructs a shared mental model (SMM), and subsequently a more dynamic team situation model, in accordance with the demands of making predictions about a dynamic team task environment (Cooke, Stout, & Salas, 2001).

This theoretical orientation to TSA has led a number of researchers to develop metrics that concentrate on the knowledge, and particularly knowledge overlap, of team members (e.g., Bolstad & Endsley, 2003). This approach is outcome-oriented and inherently limits the scope of TSA to the aggregated static (representational) operator knowledge of system state. However because many teams are faced with highly dynamic task constraints, many states of the environment may not correspond to operator knowledge (e.g., mental models), and knowledge elicitation may not be the best metric of the capability of a team to deal with these situations. Further, the strong view of TSA as knowledge overlap breaks down for large heterogeneous teams for which in which a "shared" understanding among team members is neither feasible, nor desirable.

In this regard, we have focused our efforts toward defining and measuring TSA in terms of the synthetic process of team coordination under roadblock transformation, where "roadblock" corresponds to a change introduced into the global environment of operations that pushes the task into some unfamiliar region of its state space that has performance consequences for the team. In this region of the task's state space, individual team members have their own local perceptions of the roadblock, however a coordinated perception is required in order to fully perceive and act upon the roadblock in a timely and adaptive fashion. That is, each team member perceives a different aspect of the roadblock, and these perspectives must be coordinated in order to fully perceive and act upon the roadblock. Thus TSA cannot be understood as the sum of individual team member perceptions (or for that matter, knowledge), but rather as a synthesis of the parts as a team maintains invariance under roadblock transformation *via* team coordination. In this paper we report results for teams engaged in a command and control task for a coordination-based measure of TSA called Coordinated Awareness of Situation by Teams, or CAST (Cooke & Gorman, in press).

Half of the teams performed the task in a co-located environment in which thought they communicated over headsets, they could turn away from the console to see fellow team members. The other half of the teams performed in a distributed environment using the same mode of communication as the co-located condition, but being located in separate rooms or cubicles. It was hypothesized that this subtle manipulation of co-location may negatively affect the TSA of the distributed team due to difficulties coordinating over a distance.

METHOD

Participants

Twenty three-person teams of New Mexico State University students participated in two 5-hour sessions in an unmanned air vehicle-synthetic task environment (UAV-STE; see below for a description) over seven missions per team. Individuals were compensated by payment of $6.00 *per* person hour to their student organizations. The three team-members on the highest performing team each received a $50.00 bonus. The participants were randomly assigned to team and role.

Materials & Procedure

Teams were randomly assigned to either a co-located or distributed condition. In co-located teams all team members were in the same room. In distributed teams two team members were in the same room separated by a partition, the third team member was in a different room on another floor of the building. The experiment was conducted in the Cognitive Engineering Research on Team Tasks Lab's UAV-STE (Cooke & Shope, 2005). Each team member had a specialized role: AVO (pilot), PLO (photographer), and DEMPC (navigator). Teams coordinated over microphones and headsets in order to "fly" their UAV to take photos of targets. Mission performance scores were based on a weighted sum of several variables: number of photos, mission time, fuel/film used, and time in alarm state. This study was conducted in order to identify differences between co-located and distributed teams under low and high workload. (Only relevant data are presented here, but for a complete account of hypotheses and results from all of the measures see Cooke, DeJoode, Pedersen, Gorman, Connor, & Kiekel, 2004.)

A 5-minute communication channel glitch from DEMPC to AVO was introduced when teams reached a designated point during Mission 6. The CAST scoring procedure consisted of listening to team communications around the 5-minute glitch and then checking appropriate boxes on a CAST scoresheet (Figure 1). The scoresheet consisted of four components: 1) which team members independently noted the glitch; 2) which team members discussed the glitch; 3) actions taken in order to circumvent the glitch (these correspond to firsthand perception, coordinated perception, and coordinated action in Figure 1); and 4) whether or not the team overcame the roadblock.

RESULTS

Because only one rater was used, no estimate of inter-rater reliability was available. Although the task of identifying particular phrases; e.g., "I can't hear DEMPC", seems routine enough, inter-rater reliability may be an important issue for future work. Figure 1 illustrates actual ratings made during the experiment. In Figure 1, the left side shows a CAST result where the AVO perceived the glitch and coordinated his perceptions with the DEMPC: the AVO could not hear DEMPC, but the DEMPC could hear AVO. This led to the successful coordinated action of the DEMPC channeling communications to AVO through PLO.

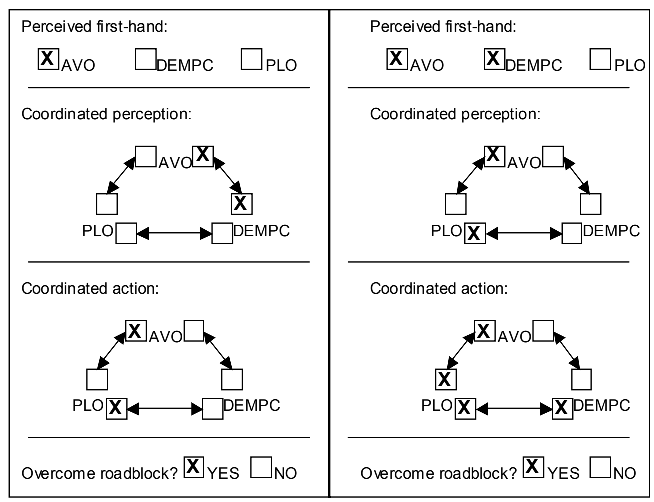

Figure 1. Score patterns using the CAST scoring sheet.

In Figure 1 the right side shows both DEMPC and AVO perceiving the glitch and establishing a coordinated perception via PLO. Subsequently PLO is involved in coordinated action as a bi-directional conduit of AVO-DEMPC communications. While both the left and right solutions overcome the glitch, one is more efficient (left) than the other (right) corresponding to better CAST-TSA overall. In fact, the right team missed a target because PLO had dedicated himself to relaying messages back and forth instead of taking pictures of targets. Notably, the knowledge-based view of TSA would presumably assess the pattern on the right, in which there is more "sharing", as indicative of higher TSA than the pattern on the left.

The pattern on the right was more common in distributed teams (6 to 2) as was PLO being involved in the coordinated perception of the glitch (6 to 4). The coordinated action that taxed PLO by making him/her a bi-directional conduit almost always occurred when PLO was involved in the coordinated perception of the glitch (7 out of 8).

To obtain CAST scores for further analyses, the ratios of checked boxes to total boxes were calculated within component: PF – perceived firsthand, CP – coordinated perception, and CA – coordinated action.

The component ratios were grouped into "none", "low", and "high" proportions. Table 1 shows the groups and the ratio(s) calculated for each group. (One team was never exposed to the glitch and was dropped.)

Several of these teams did not overcome the roadblock (n = 5). Among the teams who overcame the roadblock (n = 14) the CAST components were examined for effects of team distribution. Distribution effects were found for two of the CAST components: PF – $F\,(1, 12) = 4.5$, $p = .06$ & CA – $F\,(1, 12) = 6$, $p = .03$. The mean ratio of checked boxes for each component by distribution are listed in Table 2.

Table 1. "None", "Low", and "High" Groups and their CAST Component Scores (# in parentheses is number of teams in group).

	None	Low	High
PF	0 (1)	.33 (15)	.67 (3)
CP	0 (3)	.33 (8)	>.5 (8)
CA	0 (3)	.33 (8)	.67 (8)

Table 2. Mean CAST Component Score by Distribution.

Co-located (n = 7)		Distributed (n = 7)
PF	.33	.48
CP	.43	.57
CA	.43	.62

Distributed teams in general had significantly higher PF, but also tended to have a slightly higher rate of team member involvement in CP (*ns*). Distributed teams also had significantly more CA links in bypassing the roadblock.

In terms of overall team performance, co-located teams tended to perform worse than distributed teams on Mission 6 ($t\,(18) = -1.65$, $p = .10$). Mission 6 team performance was analyzed as a dependent variable for CAST TSA component effects using a between-subjects analysis of variance. Independent variables included controls for intercept, distribution, roadblock overcome? (yes/no), and predictors for PF, CP, and CA. The "high", "low", and "none" groups (Table 1) were used to code the CAST components. The results are presented in Table 3.

Table 3. B-S ANOVA; DV is M6 team performance.

Source	*df*	*SS*	*MS*	*F*	*p*
Distribution	1	13,728	13,728	5.2	.05
Overcome?	1	18,528	18,528	7	.02
Perc. Firsthand	2	30,635	15,318	5.8	.02
Coord. Perc.	2	29,693	14,847	5.62	.02
Coord. Act.	2	31,259	15,629	5.92	.02
Error	10	26,421	2,642	.	.
Total	18	86,333			

All three CAST TSA components were significant ($p < .05$), illustrating the salience of the glitch roadblock in terms of team performance. In Figure 2 higher levels of PF along with lower team member involvement in CP and CA predicted highest team performance.

DISCUSSION

In order to avoid the detrimental effects of the glitch roadblock on team performance, TSA should involve more than one team member perceiving the glitch, and some, but not every team member, having a hand in the coordinated perception. Similarly, coordinated action for overcoming the glitch roadblock should involve some, but not all team member links. This is contrary to views that hold that TSA is optimal when all team members share a common picture. In this case, it is more efficient performance-wise if only the essential team members are involved.

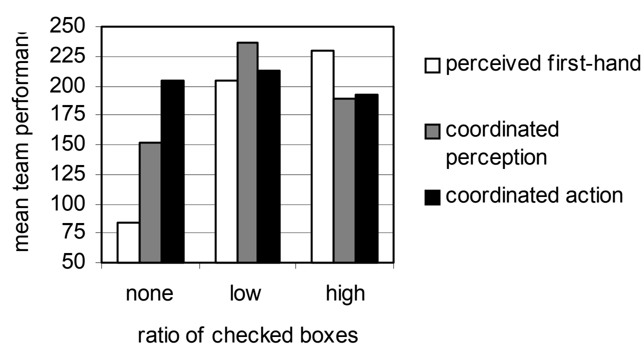

Figure 2. Mean team performance by ratio of checked boxes for CAST components.

These results lead to some very specific statements about what is involved in having good TSA. Specifically, for this task and roadblock, only certain team members needed to be aware of the roadblock, either firsthand or *via* coordinated perception. The finding supports the notion that coordinated perception involving all team members (cf. a SMM) can underlie maladaptive team behavior, in this case by tying up a team member (PLO) more than necessary in order to overcome the glitch roadblock. Interestingly, distributed teams exhibited a greater tendency to involve more team members, possibly due to the paucity of information available about the state of other team members, creating a perceived need for redundancy.

CONCLUSION

In the history of psychology researchers have sought to explain complex phenomena, such as perception, in terms of internal cognitive or memory processes. For instance, classical theories of perception involve the internal cognitive mechanisms through which "primary qualities" such as hue, wavelength, and temperature come to be perceived from impoverished "secondary qualities" such as visual, auditory, and skin sensations. However some researchers proposed more "direct" mechanisms for perception, including the coordination between a perceiver and his/her environment (e.g., Gibson, 1966).

The history of team psychology is no different. Explanations for complex team phenomena such as TSA have mostly been framed in terms of aggregate team knowledge. However, here we have demonstrated that the relatively more "direct" mechanism of adaptation to situational roadblocks *via* team coordination presents an interesting and different perspective for understanding TSA. In this regard, much of our current work focuses on expanding our TSA measurement capabilities along these lines.

As teams become more complex and heterogeneous with respect to expertise, approaches such as measuring SMMs in order to approximate TSA may not scale up to complex environments. In this regard, CAST presents the TSA researcher with a low-dimensional synthetic process for understanding how and why teams function as they do.

Team coordination is not independent of the inputs of individual team members. It does however represent a synthesis among these parts no matter how numerous or varied, and thus a low-dimensional variable useful for studying TSA regardless of the size or distribution of expertise of a team. More research is needed however in order to determine the amount of variance attributable to SMMs versus coordination processes in explaining TSA in large heterogeneous teams.

Acknowledgements

Support for this work provided by AFOSR Grant FA9550-04-1-0234.

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