Converging Minds: Assessing Team Performance Using Psychophysiological Measures

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Abstract. Effective teams are an integral component to the success and the advancement of any organization. This issue emphasizes the need to develop valid measures for team performance especially in operational environments. The use of psychophysiological data has been proposed as a candidate for developing these team-level measures. In this paper, we review past research in the field and discuss two contrasting approaches to model human cognition used in the context of teams. We then propose a test-bed for evaluating these models for human-in-the loop adaptive systems using psychophysiological measures.

Keywords: Team Performance, Team Cognition, Psychophysiology, Social Cybernetics, Information Processing, Closed-Loop Human Systems.

1 Introduction

Improvements in team performance are related to team members' understanding of the shared mental model (SMM) represented within the team [1]. This understanding implies that each team member knows his/her own capabilities, the task at hand, and the capabilities of the other teammates. Good team members use this information to mentally simulate how others on the team will react in different situations [2]. More specifically, SMM consists of the following factors: team cognition, team skills, team attitudes, team dynamics and team environment [3]. Team cognition is defined as a mechanism that produces coordinated behavior, emerging from the interplay between each team member's individual cognition and team process behaviors such as coordination and communication [4]. Understanding team cognition is a key aspect for predicting team performance [1].

Measurement of team cognition is still in its initial stages. The lack of research in this field [5] may be attributed to the inadequate development of the construct itself along with confusion over how these cognitive variables can be measured at a team level. Even so, theories governing the construct of team cognition continue to be solidified with the establishment of related terminology and methodologies [4]. Studies in several laboratory settings have provided a better understanding of the candidate techniques for measuring team cognition. In this paper, we will describe relevant results from such studies. We also describe two opposing views on cognition within

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individual/teams, namely social cybernetics and information processing. Finally, we propose a test-bed for evaluating these two models using psychophysiological measures.

2 Previous Work

Kiekel et al. [6] attempted to use voice communication data to evaluate team performance. In this study, the authors collected communication logs from a team of three members performing a task of flying a simulated plane over 10 missions. Changes in dominance patterns (how much each team member spoke) for each mission were then analyzed. The results showed that higher numbers of distinct dominance patterns in a mission correlated with poorer team performance.

Another study by Henning et al. [7] made use of psychophysiological data to determine team performance. The authors applied their cybernetic model of social-psychophysiological compliance (SPC) and evaluated it as a predictor of team performance. SPC, in this regard, predicts that psychophysiological measures between team members will synchronize when team performance is optimal because of the ability of good team members to anticipate each other's responding. As a part of this study, 18 teams of two participants each were tasked with manipulating a simulated object through a complex two dimensional path. SPC was calculated from heart rate variability (HRV), skin conductance response (SCR) and respiration data and cross correlated between team members. The results showed significant coherence among the psychophysiological measures for high performing teams. Based on these results, the authors claim SPC not only effectively predicts team performance, but provides a reliable means to trigger adaptive automation.

3 Social Cybernetics

The study by Henning et al. [7] is based on the cybernetics perspective. This perspective views motor behavior as a means of self-regulation via effects of motor activity on cardio-respiration, hormonal activity and other physiological systems in addition to its role in body locomotion. [8]. The cybernetics perspective for one person is extended to a social context with multiple persons interacting with each other. This theory is based upon the hypothesis that an individual can control sensory feedback not only from their own behavioral movements, but also from others with whom he/she is interacting. The cybernetics approach applied to teams is in contrast to the information processing approach, which views all motor activity as end event following series of mental processing steps. In an extension of the virtual object manipulation study described above Henning et al. [9] evaluated the use of SPC as a predictor by varying the difficulty level of task as a function of the SPC metric. In *matched condition* the difficulty level was increased when SPC indicated that the team could handle increased task demand and lowered when SPC indicated that the team could not. In the *unmatched condition,* the difficulty level was decreased when SPC indicated that the team could handle increased task demand and vice versa. Task performance was analyzed for both conditions and the error of tracking was found to be lower

in the *matched condition.* However this was accompanied with an increase in task completion time.

4 Information Processing

The social cybernetics view opposes the information processing view, in which the motor actions performed are considered as the end result of mental process. Within an augmented cognition framework, an information processing approach focuses on determining the instantaneous cognitive load using physiological sensors. Mitigation strategies such as task scheduling, modality encoding are sketched to cope for individuals performing under stress. Task sharing and offloading is mentioned as an addition when the approach is extended to a team environment [12]. Other mitigation strategies such as automation of information acquisition and automation of information analysis are also suggested, with a caution that automating the decision making process would hinder the team performance [13]. The effectiveness of these mitigations is usually measured with the NASA Task Load Index [14]. The use of psychophysiological sensors to predict the mental workload is an unobtrusive method with the potential to estimate the workload in real time.

5 Test-Bed for Evaluation of Different Theories

The challenges for bringing the measurement into an operational environment are numerous. The architecture described in [10] was developed to provide mitigation to a single operator with psychophysiological sensors. In this architecture the cognitive state of the operator is estimated by multiple sensor data streams. Salient features extracted from the streams are further classified into levels of cognitive states. This architecture can be extended to a team of operators as shown in Figure 1. Using the social cybernetics model described above, the sensor data from a team of operators could be combined into a set of features (such as metric of similarity of HRV, GSR data) and these features could be classified into levels of compliances. These levels could then drive a mitigation which adapts to the over-all level of compliance between the team members to suggest an appropriate strategy.

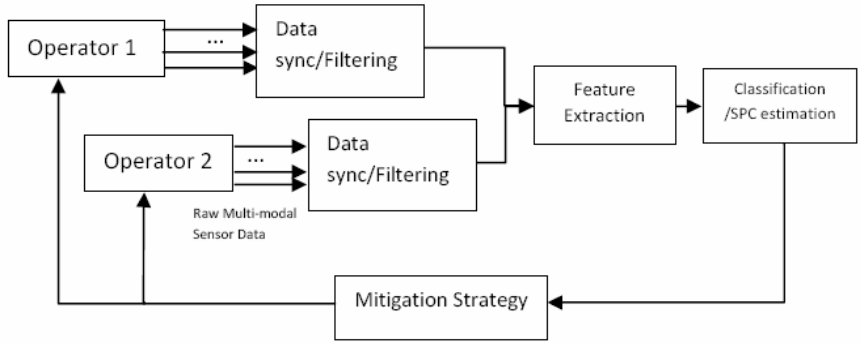

Fig. 1. Test-bed based on social cybernetics model

To test the information processing model for teams, cognitive state estimation of each of the operators in the team must be done (Figure 2). These individual estimates are then used to consider adaptations to suite the cognitive needs of each of the team members.

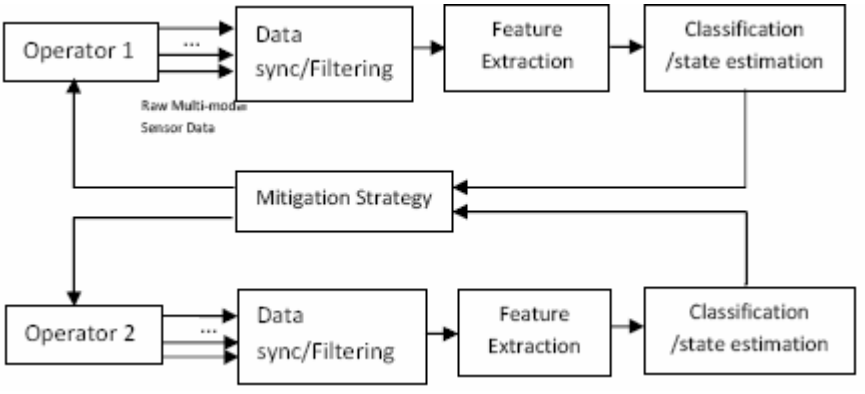

Fig. 2. Test-bed based on information processing model

The differences between these two models as seen from figures 1 and 2 are, in social cybernetic model, a single estimation of compliance metric (SPC) drives the mitigation, and same mitigation is applied to all the members of the team. In the information processing model, cognitive state estimations from all the operators is evaluated separately by the mitigation engine and adaptations are made reflecting the current need of each operator. As suggested by Henning et al. [11], using the social cybernetic model, a display of trajectory of SPC over time in a shared display to all the operators could also render helpful in achieving high over all team performance.

The model based on social cybernetics (Figure 1) would be only effective when all the operators are performing the same kind of synchronized task (such as, the laboratory experiment in section 2, in which two team members guided a virtual heavy object through a maze). In situations which require the operators to perform mutually exclusive tasks, the SPC might not be a good indicator of the overall team performance. In such cases the two models described above could be augmented where the SPC would become a part of individual cognitive estimates, and it could be used by the mitigation engine at appropriate times.

6 Conclusion and Future Work

In this paper we have sketched a test-bed framework for testing two models of cognition (social cybernetics and information processing). Each of these models holds contrasting views about cognition. Testing the usability of these models in terms of task specificity is essential before deploying any model in operational environment. In our future work, we intend to design experiments that involve tasks that require team members to perform compensatory actions (i.e. similar to maneuvering a virtual

object in a maze) and compare them to tasks requiring members to perform mutually exclusive actions. Our goal then is to analyze the physiological data and find if there exists any relationship between the type of cognition model and team performance.

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