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Macrocognition in Submarine Command and Control: A Comparison of three Simulated Operational Scenarios

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Submarine command and control operations are not well understood, but they are an exemplar of macrocognition. For the first time, this study compares three operational scenarios in a simulated submarine control room: returning to periscope depth (RTPD), inshore operations (INSO), and dived tracking of contact (DT). The event analysis of systematic teamwork (EAST) method was used to model macrocognition by way of social, task, and information networks. Results indicate that the composition of the networks differed significantly depending upon operation type and demand. The statistical differences reveal how macrocognitive processes such as situation assessment, coordination, and problem detection are context dependent and drive the attainment of team knowledge to suit operational requirements. The Officer of the Watch consistently had the highest centrality of all operators, highlighting the importance of this operator in utilising team knowledge to inform tactical decisions. Implications are discussed alongside suggestions for future work.

General Audience Summary

A team is a collection of individuals working together towards a higher goal, often with the support of technologies to achieve such aims. The processes, referred to as macrocognition, which facilitate teams of individuals working together is complex and not well understood. Submarine command and control is generally not well explored in the literature because access is often not possible. The current paper aimed to model the macrocognition of submarine command and control by comparing three operational scenarios: returning to periscope depth (i.e., getting the submarine from safe depth to periscope depth), inshore operations (i.e., costal protection and reconnaissance), and dived tracking of contact (i.e., tracking another vessel—either on the surface or subsurface). This study explored how macrocognitive processes (such as situation assessment, coordination, and problem detection) differ depending upon operational requirements. The event analysis of systematic teamwork (EAST) method was used to model macrocognition by way of social, task, and information networks. The networks were generated from the transcripts of ten teams of eight novice individuals that were trained to be representative of a submarine command team in a submarine control room simulator. The network metrics were statistically compared to examine differences in their composition that reveal context-dependent differences in macrocognitive processes. Results indicated that junior operators in the command team were responsible for situation assessments, which was supported by senior command team members via the completion of coordination and problem-detection processes. The most senior members of the command team complete adaption-based processes to rectify mistakes or improve the tactical picture which is the summation of team knowledge. Insights are provided into future research ideas and recommendations to improve future submarine command and control operations.

Keywords: Submarine, Macrocognition, Team work, Communications, Networks

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A team is a collection of individuals who interact with varying levels of interdependence for the achievement of shared goals (Cooke, Gorman, & Kiekel, 2008; Salas, Shuffler, Thayer, Bedwell, & Lazzara, 2015). There is often a reliance on supporting technologies to enable team-based processes and facilitate adequate interdependence (Letsky, Warner, Fiore, Rosen, & Salas, 2007). A sociotechnical system is defined as the interaction of human operators and technology, often with growing interdependence in pursuit of purposeful, goal-directed behaviours (Walker, Stanton, Salmon, & Jenkins, 2009). The effective engineering of complex sociotechnical systems to maximise collaborative activity requires an understanding of macrocognition as it naturally occurs in complex decision making environments (Klein et al., 2003). A submarine control room relies on effective interaction between multiple technological and human agents for optimal performance. It is an excellent example of a complex sociotechnical system (Shattuck & Miller, 2006; Stanton, 2014; Walker et al., 2009). Submarine control rooms therefore provide an interesting context to examine macrocognition (Driskell, Salas, & Driskell, 2017; Letsky et al., 2007).

Macrocognition

The field of naturalistic decision making (NDM) attempts to understand how people make decisions in applied environments rather than in artificial laboratory settings (Klein, 2015). Macrocognition is defined as a collection of processes or cognitive functions that are performed in complex naturalistic decision-making environments, providing a framework for understanding processing beyond the singular level (Fiore, Smith-Jentsch, Salas, Warner, & Letsky, 2010; Klein et al., 2003). Decision making in naturalistic environments relies on experience-based pattern matching; therefore a key challenge for decision makers is making sense of the conditions rather than choosing between multiple options (Klein, 2015). The NDM view of macrocognition proposes a set of emergent functions and processes (e.g., situation assessment, coordination, and problem detection) that describe how complex sociotechnical systems operate (Klein et al., 2003; Schraagen, Klein, & Hoffman, 2008).

There is debate regarding the composition of macrocognitive processes and how they might best be measured (Wildman, Salas, & Scott, 2014). The team cognition perspective of macrocognition emphasises the coordinating mechanisms that facilitate collaborative activity amongst individuals to build and exchange knowledge in service of higher-order team goals (Fiore et al., 2010). This divergence in perspectives is not necessarily problematic (e.g., coordination is listed as a macrocognitive process in the NDM literature) as it is acknowledged that currently proposed macrocognitive functions will likely change as research in the field progresses (Klein et al., 2003). A frequent criticism of NDM research is that explanations tend to be vague regarding the underlying process governing behaviour and lack formalisation due to an absence of measurable parameters (Thomson, Lebiere, Anderson, & Staszewski, 2015). Therefore, a key challenge for understanding macrocognition is the capacity to quantify such processes without losing the essence of the NDM perspective via oversimplification of complex natural environments (Klein et al., 2003; Wildman et al., 2014).

An eloquent description of team cognition research describes two separate approaches to team cognition as being *in the head* or *between the heads* (Cooke et al., 2008). Understanding the processes that drive and facilitate the switching of knowledge between the internalised individual team members to an externalised team construct, and vice versa, is regarded as an investigation of macrocognitive processes (Cooke et al., 2008; Fiore et al., 2010; Letsky et al., 2007; Wildman et al., 2014). It may not be possible to examine all macrocognitive processes from this perspective; nevertheless, it is important to encourage research at the macrocognitive level of description (Klein et al., 2003). It has been proposed that analysis of team communication allows for direct observation of cognition occurring between the heads (Cooke et al., 2008).

Submarine Command and Control

A submarine control room is analogous to a human mind, containing a range of sensors that act as the ears (sonar), eyes (periscope), and vestibular system (gyroscopes) of the submarine (see Figure 1). Human cognition relies on working memory (WM), a limited capacity system responsible for the temporary storage and manipulation of task-relevant information from different sensory modalities and internal memory constructs (Baddeley, 2000; Radvansky, 2017). Understanding how submarine command teams make sense of their environment is challenging due to the complexities involved in the generation and development of a tactical picture by multiple operators (Dominguez, Long, Miller, & Wiggins, 2006; Hicks, Stoyen, & Zhu, 2001; Stanton & Roberts, 2017). As with WM, the capacity of the command team is limited, and synthesis of information from different sensors relies on effective teamwork and communication. Such processes can become the limiting factor in determining workload of the team, rather than the work itself (Carletta, Anderson, & Mcewan, 2000; Salas, Burke, & Samman, 2001). The cognitive capacity of individual operators is one factor that will determine the capacity of the team, via the data-information-knowledge cycle that creates internalised knowledge (Fiore et al., 2010). However, between-the-heads macrocognitive processes guide team knowledge building, which is the focus of the current work.

In a submarine control room, environmental sound propagation is received by sonar arrays, then processed and represented on an interface for sonar operators to monitor (Bateman, 2011; Shar & Li, 2000; Zarnich, 1999). The sonar operators' interactions with sonar interfaces facilitate the conversion of sonar data to information as part of individual knowledge-building processes (Fiore et al., 2010). The periscope operator performs similar duties using visual data, and the ship control operator comprehends processed gyroscopic data concerning own-submarine parameters (Stanton & Roberts, 2017). This provides insight into the technological aspects of the command system including technology-to-technology information transition and technological support for the individual knowledge-building processes. However, it does not

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