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Go Deeper, Go Deeper: Understanding submarine command and control during the completion of dived tracking operations

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ABSTRACT

This is a world's first-of-a-kind study providing empirical evidence for understanding submarine control room performance when completing higher and lower demand Dived Tracking (DT) scenarios. A submarine control room simulator was built, using a non-commercial version of Dangerous Waters as the simulation engine. The creation of networked workstations allowed a team of nine operators to perform tasks completed by submarine command teams during DT. The Event Analysis of Systemic Teamwork (EAST) method was used to model the social, task and information networks and describe command team performance. Ten teams were recruited for the study, affording statistical comparisons of how command team roles and level of demand affected performance. Results indicate that command teams can covertly DT a contact differently depending on demand (e.g. volume of contacts). In low demand it was possible to use periscope more often than in high demand, in a 'duck-and-run' fashion. Therefore, the type of information and frequency of particular task completion, was significantly different between the higher and lower demand conditions. This resulted in different operators in the command team experiencing greater demand depending on how the DT mission objective was completed. Potential bottlenecks in the command team were identified and implications are discussed alongside suggestions for future work.

1. Introduction

1.1. Submarine command and control: dived tracking

A dive tracking (DT) operation requires a submarine command team to covertly track a 'priority' contact whilst simultaneously ensuring overall submarine safety via adequate track management of the entire tactical picture (Loft et al., 2016; Bateman, 2011; Loft et al., 2013; Huf and French, 2004). Submarines are equipped with a range of sensors and instruments which generate a large amount of data that operators in the control room must integrate to facilitate the generation of a tactical picture (Dominguez et al., 2006; Huf et al., 2004; Shattuck and Miller, 2006; Stanton, 2014; Stanton and Bessell, 2014). A DT operation typically requires a submarine to operate below periscope depth (63 m) to ensure covertness, reducing the number of instruments available (e.g. periscope) to the command team, forcing a reliance on passive sonar. The accuracy of passive sonar for developing the tactical picture can be greatly affected by oceanographic conditions (e.g. water temperature) and background noise (e.g. multiple vessels) (Zarnich, 1999; Ogden et al., 2011; Kirschenbaum, 2001). This requires the submarine command team to build a tactical picture from large volumes of ambiguous information, operating with great uncertainty (Kirschenbaum, 2001). Even DT of surface vessels from deep is a challenge, particularly when military surface vessels use technology to reduce chances of detection (Koubeissi et al., 2013; Xuan and Li, 2006).

The development of new technologies and new methods for fusing data when tracking priority contacts using external equipment (e.g. sonobuoys) could extend capability (Wang et al., 2011). However, the placement of such technologies is not always possible due to logistical, operational or legal restrictions. Therefore the ability of submarines to self-sufficiently covertly track other vessels remains a critical operation (Bateman, 2011). This is particularly important as a shift in the tactical deployment of submarines by some nations is likely to lead to an increase in the requirement to dive track other submarines (Li, 2009; Bateman, 2011). Research has sought to develop new software algorithms and architectures to make the tracking of contacts by submarines more efficient and accurate (Shar and Li, 2000; Wang et al., 2011; Lim, 2012). However, such work does not examine how the technology might be used within the submarine control room and the impact it may have on the sociotechnical system as a whole (Walker et al., 2009). Therefore, a primary aim of the current work is to evaluate submarine control rooms from a sociotechnical perspective. Providing insight and

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a baseline comparator, to understand how new data and/or operators, might be optimally integrated into the system.

1.2. Sociotechnical systems – control rooms

A sociotechnical system is defined as the interaction of human operators and technology, to pursue broader goal-directed behaviours creating the conditions for successful overall performance (Walker et al., 2009). In sociotechnical systems, effective sharing of information is critical as cognitive processes and Situation Awareness (SA) are not held by one agent or individual but rather are distributed across the control room (Stanton, 2014, 2016; Read et al., 2015). The capacity to DT a vessel relies on the commanding officer having an accurate tactical picture and reliable information concerning the priority contact's behaviour. The commanding officer is ultimately responsible for the safety of the submarine but decision effectiveness relies on the effective integration of large volumes of information from disparate sources, both technological and human (Dominguez et al., 2006). The sociotechnical systems perspective therefore offers a valid theoretical grounding for understanding submarine control room functionality (Stanton, 2014). Understanding the distribution and sharing of information within command teams can help to inform the optimal design of control rooms and technologies (e.g. interfaces) within them across many domains (Stanton, 2011, 2014; Salas et al., 2001; Lee and Kantowitz, 2005). The manner in which a team is configured and how technology supports communication can also influence their effectiveness (Stanton et al., 2015; Espevik et al., 2006).

The ability of submarine control room teams to track contacts has been investigated previously (Loft et al., 2016; Loft et al., 2013; Huf and French, 2004). Such work has provided valuable insight into the SA of track management. However, this work was individualistic and did not approach the task from a sociotechnical systems perspective. A returning to periscope depth scenario has been investigated from a sociotechnical perspective, providing insights into the functions of a submarine command team (Stanton, 2014; Stanton and Bessell, 2014). However, it is likely that differences in control room functionality will be evident in different operational contexts such as a DT or inshore operation compared to a return to periscope depth (Stanton, 2014; Duryea et al., 2008; Bateman, 2011; Stone et al., 2009). The ability of a submarine command team to track contacts has been approached from a sociotechnical perspective (Hunter et al., 2014). Such work outlined an experimental design approach, but the empirical contribution of the work was limited to two teams. A great challenge in this pursuit is the recruitment of large numbers of teams to provide evidence with good statistical power that is generalizable. This issue has been highlighted in studies comparing a large individualistic student cohort to a smaller team-based expert cohort of submariners, where great differences in time taken to establish SA and tactical picture quality were observed (Loft et al., 2016). Nevertheless, the recruitment of novice participants with effective training procedures and relative task fidelity has been demonstrated to be a good approach for balancing ecological validity and statistical reliability in the military domain (Walker et al., 2010). Therefore, the recruitment of larger numbers of novice teams provides an opportunity to provide empirically robust insights into submarine command team functionality from a sociotechnical and macrocognitive perspective (Keyton et al., 2010; Wallace and Hinsz, 2010). This can provide formalisation of constructs and clear defining measurable parameters to inform evidence based design of future control rooms (Thomson et al., 2015).

1.3. Optimising control rooms of the future

As technology continues to rapidly advance, sociotechnical systems are primed for revolutionary changes in ways of working to increase capability (Roco and Bainbridge, 2003; Showalter, 2005). This drive is not only evident for the submarine domain (Stanton, 2014), but also for surface vessels (Lützhöft and Dekker, 2002; Negahdaripour and Firoozfam, 2006), aviation (Rudisill, 2000; Bruce et al., 1998; Stanton et al., 2016) and gas/electric/nuclear power plants (Santos et al., 2008; Stanton et al., 2009a,b; Stanton et al., 2010). In many of these domains control rooms are required, their commonality being a reliance upon effective communication and teamwork. Such processes can be the determining factor in terms of team workload rather than the work itself (Salas et al., 2008; Stanton, 2011; Salas et al., 2001; Carletta et al., 2000).

A critical challenge when optimising the design and operation of control rooms is that they are complex by nature and as a result knowledge is not easily attained and shared by operators, manufacturers and researchers alike. This is compounded by the fact that control rooms in many domains manage hazardous systems and are often subject to heightened security and regulation (Roberts et al., 2015). Understanding the strengths and weaknesses of control rooms from a sociotechnical systems perspective across different domains, operations and with different levels of demand will facilitate this. It is important to understand how a submarine DT other vessels in conditions of both high and low demand (e.g. varied number of contacts), to inform the design of adaptive, flexible control rooms. Primarily because submarines of the future will encounter greater variability in demand due to changing numbers of vessels in the water, both surface and submerged, coupled with variations in the primary locations that submarine operations are completed (Bateman, 2011; Duryea et al., 2008).

The current work sought to examine DT operations from a sociotechnical systems perspective. The examination of multiple command teams facilitated empirical examination of command team performance. We also investigated the effect of different operational demand on command team strategies by using both higher and lower demand DT scenarios.

2. Method

2.1. Participants

A total of 71 males and 9 females participated with an age range of 18–55 (Mean = 26.83, SD = 8.69) from a variety of backgrounds primarily including undergraduate students and graduate recruits from Ministry of Defence supported companies. The 10 teams of 8 individuals (80 participants in total) were recruited opportunistically using posters and presentations at military Human Factors conferences. One team were currently operational submariners from the British Royal Navy. This team was used as a subject matter expert 'gold-standard' to assess the fidelity of the simulator and tasks. The metrics derived from the expert team revealed similar directions to the novice teams (e.g. did not violate assumptions of statistical analysis) and so it was decided to include this team in the analysis process to enhance statistical power. Participation in the study was voluntary.

2.2. Equipment - the submarine control room simulator

A submarine simulator based upon a currently operational submarine was designed and built by the research team (see Roberts et al., 2015 for full description of simulator). The simulator was comprised of 9 network workstations (see Fig. 1) that were running Dangerous Waters (DW) as the simulation engine. DW is a naval warfare simulation developed by Sonalysts which features many player-controllable units from a submarine control room. The workstations are networked so operators can function as a command team in support of global mission objectives. Subject matter experts informed the choosing of stations to include in the simulator to be representative of an operational submarine control room. The stations chosen were a Periscope station (PERI), a Ship Control station (SHC), two Sonar Operator stations (SOP), two Target Motion Analysis stations (TMA), a Sonar Controller station (SOC), an Operations Officer station (OPSO) and an Officer of