Examining the effect of reduced crew sizes on submarine command team workload

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ABSTRACT

The Command Team Experimental Test-Bed (ComTET) is a body of work that aims to understand the current functionality of submarine command teams and future ways of working. To facilitate their research, the ComTET team built a submarine control room simulator for testing purposes. Previous research from the ComTET research program ran baseline testing to understand current functionalities in the control room. This generated a number of recommendations that informed the design of a new control room configuration, whereby the crew size was reduced by removing one Sonar Operator and one Target Motion Analyst Operator. This study tested 70 participants (ten teams of seven individuals), all of which received general maritime and role-specific training using the ComTET tutorial package. Each team was required to complete high and low demand versions of three scenario types: Return to Periscope Depth, Inshore Operations, and Dived Tracking. Following the completion of each scenario, the participants' subjective workload was self-reported using an electronic version of the Bedford Workload scale. The results provided in this paper show a preliminary analysis of workload scores from a subset of four teams. Teams were taken from both the baseline and reduced crew size configuration. Results suggested that the subjective workload of operators was affected by scenario demand and type. Additionally, the results indicate that the reduction of crew size increased the workload placed on operators in the command team. Therefore, submarine command teams with reduced crew sizes are more likely to be faced with higher workload levels during submarine operations.

KEYWORDS

Submarine, workload, control room

Introduction

Contemporary submarine control rooms are a product of years of utilisation within the Navy, nevertheless, there is still room for improvement (Stanton, 2014). Submarine command teams of the future will be required to process larger volumes of data from new sensors with improved capabilities (Duryea, Lindstrom, & Sayegh, 2008). These sensors will require operators to process larger quantities of data (Dominguez et al., 2006), whilst potentially using additional displays in the control room (Chalmers, Easter, & Potter, 2000). It seems reasonable to assume that given the availability of additional data, the workload of operators is also likely to increase. Workload is defined as the "perceived relationship between the amount of mental processing capability or resources and the amount required by the task" (Hart & Staveland, 1988). High workload can lead to operators using coping strategies that can be detrimental to overall performance (e.g., not completing tasks in order) (Hart & Staveland, 1988). Also, high levels of workload can create other issues such as increasing task completion times (Biondi et al., 2020) and impairing performance (Owens et al., 2018). Both over- and under- load can lead to impaired operator performance and increase the likelihood of operator error (Ayaz et al., 2012). Therefore, it is critical that the workload of operators in the control room is assessed to ensure their performance is not being hindered by work over- and under load. To achieve optimal performance, workload should be at medium levels of arousal according to the Yerkes-Dodson Law (Wickens & Hollands, 2000). However, to further complicate the issue of operator workload in future submarine command teams, there is also the possibility of reduced crew sizes (Roberts, Stanton, & Fay, 2015). This is likely to occur because of the substantial economic savings associated with reduced crew sizes (Allender, 2000). It is therefore imperative that we have a better understanding of how command team performance and operational safety will be impacted by (i) the availability of larger volumes of data that are afforded by advancements in sensor-based technologies and (ii) reduced crew sizes (Salotti, Heidmann, & Suhir, 2014). This understanding will contribute to determining the efficacy of crew reduction and examine whether the command team's capacity is being optimally used (Roberts et al., 2020a, 2020b).

The Command Team Experimental Test-Bed (ComTET) is a body of work that aims to understand the current functionality of submarine command teams and future ways of working**.** The design of the current study was informed by previous work which aimed to explore current ways of working within submarine command teams (baseline study; Roberts, Stanton, & Fay, 2017). From the baseline study, several recommendations were made to enhance the efficiency of control room operations. One recommendation was to co-locate the Sonar Controller (SOC) and the Operations Officer (OPSO) to reduce workload and address the 'bottleneck' found between the operators (Stanton & Roberts, 2017). This informed the design of the co-location configuration whereby the Sonar Operators (SOP) and Target Motion Analyst Operators (TMA) were seated next to each other. Using this novel configuration, a study was also undertaken to examine the impact of reduced crew sizes in which one SOP and one TMA Operator were removed (Stanton & Roberts, 2020a). The decision to remove these operators was informed by Subject Matter Experts (SMEs) and baseline findings that suggested the pair of SOPs and TMAs shared similar tasks, therefore removing one SOP and TMA would reduce the command teams' capacity, rather than removing functionality (Roberts et al., 2019).

Method

Participants

Ten teams of five were recruited to take part in this reduced crew size study (50 participants). ComTET used seven operator roles in the command team, with the role of Officer of the Watch (OOW) and Ship Control Officer (SHC) being carried out by an experimenter. This is in contrast to teams of eight that took part in the baseline study (80 participants). As the testing for baseline and reduced crew size configurations used different participants a between-subject design is utilised. Participants were recruited opportunistically using posters and contacting local groups with relevant interests to the study. The use of novice participants was deemed acceptable as previous research found few significant differences in performance between novice and expert teams (Walker et al., 2010). The study protocol received ethical approval from the Ministry of Defence Research Ethics Council (MODREC) (Protocol No: 551/MODREC/14) and the University of Southampton Research Ethics Committee (Protocol No 10099).

Apparatus

A submarine control room simulator, from herein referred to as the ComTET facility, was designed and built to be representative of an operational Royal Navy submarine (for a full description of the build see Roberts, Stanton, & Fay, 2015). The simulator consists of nine networked workstations each installed with the simulation engine Dangerous Waters (DW). Three scenarios at two levels of demand (high and low) were designed in DW with input from Subject Matter Experts (SME) to be representative of scenarios typically experienced by operational command teams (see table 1). The high demand scenarios were designed to be more difficult than the low demand scenarios due to the higher number of contacts presented to the command team. Each scenario lasted approximately 45 minutes and the order of scenario completion was counterbalanced across teams to prevent order effects.

The roles included in the simulation were informed by SMEs. These roles included an: OPSO, SOC, SOP (x2), TMA (x2), a Periscope Operator (PERI), and Ship Control Operator (SHC). In the reduced crew size study, there was only one SOP and TMA. In both the baseline study and the reduced crew size study, the role of the OOW was carried out by an experimenter to tactically guide the scenarios.

The Bedford Workload scale was used to examine the subjective workload of operators. This measures workload in terms of 'spare capacity' on a scale of one, where workload was considered insignificant, to ten where the task was abandoned due to work overload (Roscoe & Ellis, 1990). The scale has been found to have good applications in practical settings such as being used extensively to measure the workload of military and commercial aviation pilots (Roscoe & Ellis, 1990).

Table 1: Description of scenarios completed

Name	Demand	Number of Contacts	Description
Return to Periscope Depth (RTPD)	Low	4 – Fishing	RTPD to send intelligence within a large temporal window. All contacts held must be located and ranged to find an optimal course for RTPD. The scenario is complete once periscope is raised and all contacts are marked.
	High	9 – Fishing 3 – Catamaran 1 – Biological	Submarine has a severe damage and must RTPD as quickly as possible. Contacts need to be ranged to find the best RTPD course.
Dived Tracking (DT)	Low	3 – Fishing 1 – Sailboat 1 – Nimitz	Begin at periscope depth, locate and track the priority contact, Nimitz (warship). The scenario ends when the Nimitz has been successfully tracked and all contacts have been ranged.
	High	7 – Fishing 2 – Merchant 1 – Nimitz	Locate and track priority contact, Nimitz after an emergency go deep procedure.
Inshore Operations (INSO)	Low	3 – Merchant 1 – yacht 1 – Freighter	Navigate submarine inshore to get intelligence on a building. Scenario ends when the periscope photographs the building on land.
	High	2 – Merchant 1 – Powerboat 5 – Fishing	Identify and track a suspicious vessel inshore and gather intelligence.

Procedure

On the first day (training day) participants watched a number of tutorial videos that introduced them to submarine specific concepts such as bearing, course, speed, and range. Following this, participants watched operator specific tutorials based on their assigned roles. Participants were then given the opportunity to practice their tasks individually, before coming together at the end of the day to practice as a functional command team.

On the second day (testing day), participants completed a final practice scenario during which experimenters assessed whether the participants displayed adequate performance or if they required additional training. A participant would be considered to show adequate performance if they could perform the tasks required for their role, for example a TMA operator forming a solution on a contact held by the submarine. Following the completion of the practice scenario, participants were given a short break before commencing with the six scenarios. At the beginning of the scenarios, all recording devices were started and the OOW delivered a brief outlining the mission objectives (see Table 1). The scenario ended when the mission objective was achieved. The participants then self-reported their subjective workload levels by completing an electronic version of the Bedford Workload Scale. Participants were then given a short break before the beginning of the following scenario. Regular breaks and refreshments were provided to participants over both days.

Results

Baseline Bedford Scores

The ComTET team is in the process of analysing the data from all ten teams that completed the testing. Therefore, a subset of four teams were taken each from the baseline study and the reduced crew study. These results are presented to provide an indicator of the direction of the work. The means and standard deviations of baseline Bedford scores for the low and high demand scenarios are presented in Table 2 and Figure 1.

The results showed that across all scenario types, participants' Bedford scores were greater in the high demand scenario than in the low demand scenario. This indicates that they believed the high demand scenarios were more difficult than the low demand (see Table 2). Out of the three scenario types the RTPD scenarios had the greatest difference in Bedford scores between high and low demand. This is likely because the RTPD high scenario had the highest number of contacts and the RTPD low scenario had the smallest number of contacts out of all the scenarios. Furthermore, mean scores for the high and low DT scenarios had the least difference when compared to all the scenarios.

Table 2: Means and Standard Deviations of Baseline and Reduced Crew Size Bedford scores for RTPD, INSO and DT low and high demand

	Baseline		Reduced Crew Size	
Scenario	**Low Demand**	**High Demand**	**Low Demand**	**High Demand**
RTPD	3.13 ± 1.36	5.38 ± 2.85	3.38 ± 1.75	5.89 ± 2.31
INSO	3.33 ± 1.99	5.19 ± 2.58	3.17 ± 1.28	6.36 ± 2.74
DT	3.64 ± 1.88	4.66 ± 2.19	4.33 ± 1.47	5.52 ± 2.42

Reduced Crew Size Bedford Scores

The means and standard deviations of the Reduced crew size Bedford scores are shown in Table 2 and Figure 1. The results for the reduced crew size found that across all scenario types, participant's Bedford scores were higher in the high demand scenario than in the low demand scenario (see Table 2). This indicates that the high demand scenario was found to be more difficult by the participants. When comparing all the scenarios, the INSO low demand scenario had the lowest workload score and the INSO high demand had the highest. Furthermore, the workload scores for the DT scenario were the closest out of all the scenarios.

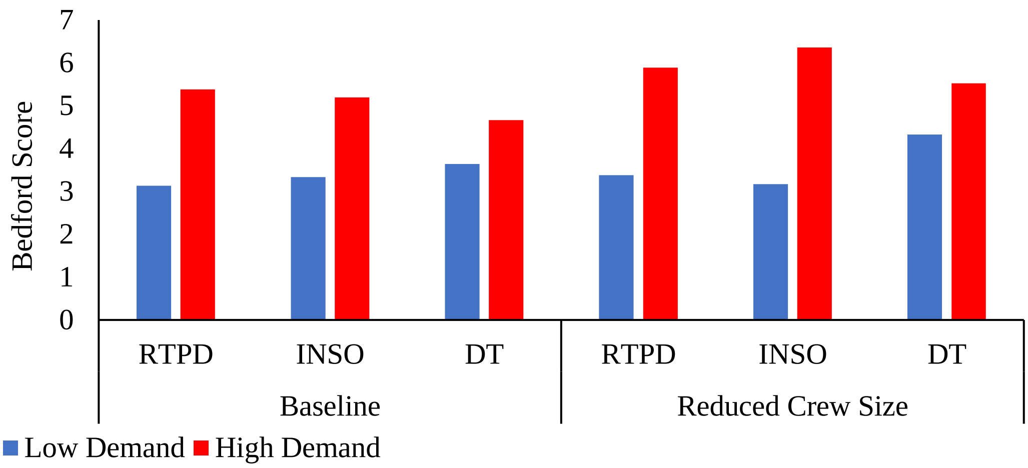

Figure 1: Baseline and Reduced Crew Size Bedford scores for RTPD, INSO and DT low and high demand

When comparing the baseline study to the reduced crew size study a number of similarities were found. In both studies, Bedford scores were greater in the high demand than the low demand scenarios. However, the scenario type that elicited the greatest Bedford scores differed. In the baseline study the RTPD high demand had the highest workload scores, but in the reduced crew size study, the INSO high demand scenario had the highest Bedford scores. It appears that a reduction in crew size led to an increase in Bedford scores for INSO and DT scenario types but not for RTPD.

Discussion

In the current work, the subjective workload of a subset of operators in a submarine command team with a reduced crew size was compared to a baseline study which was conducted by Roberts et al. (2017). Results indicated that the design of high and low demand scenarios were representative of submarine procedures at differing levels of demand as there were observed differences in workload scores, with operators reporting higher workload scores in the high demand scenarios. Previous research indicated seating the command team in a co-location configuration aided in improving operators' capability to cope with increased demand (Roberts et al., 2018). Therefore, it is important to note, the findings presented in the current work are from a co-located, reduced crew which may have also affected the command teams' subjective workload scores when working in a reduced crew size team.

Overall, a reduced crew size configuration is associated with increased workload scores across all scenarios (except for INSO low demand). The Bedford workload scores observed during the reduced crew size configuration, low demand scenarios were numerically similar to the baseline low demand scores. In part this could be due to the reduced crew study co-locating the operators, removing the bottleneck of information that was identified in the baseline study (Roberts et al., 2017). In addition, the single TMA and SOP operators could also handle the smaller number of contacts that were used in the low demand scenarios (Stanton & Roberts, 2020b). As there were fewer contacts in the low demand scenarios, the command team still had spare capacity which could be used to process information from additional sensors in the control room (Hamburger et al., 2011). This is particularly useful given that technological advancements will require operators to handle more data from new and advanced sensors (Dominguez et al., 2006).

However, the scores in the high demand scenarios during the reduced crew size study were greater than those in the baseline high demand scenarios. This difference may indicate that the number of contacts being processed by operators exceeded their capacity (Stanton & Roberts, 2020a). The capacity of operators could have been maximised to the point where operators no longer had spare capacity to respond to changes in priorities (Stanton & Roberts, 2020a). This scenario demand also contributed to the increased workload scores with the high demand scenario types having higher workload scores self-reported in the reduced size configuration. Therefore, indicating that with a reduced crew size more difficulties would be experienced during the high demand than the low demand scenarios.

Whilst preliminary results suggest a marked difference in workload scores between the baseline and reduced crew configuration, much more research is needed to allow for empirical comparisons to be made. More research is also needed to determine the impact of a reduced crew configuration on picture accuracy, submarine safety and maintenance in numerous operational scenarios (Stanton & Roberts, 2020a). In addition to new sensors, the implementation of automation in control rooms may also change the roles of operators. Research has found that automation can support operator performance during various levels of task load (Chen et al., 2014). This suggests automation could alleviate the workload of operators and would serve to support the reduction of crew sizing. Hence, future research should also look at reduced crew sizes operating alongside automated technology.

To conclude, this current work indicates that using a command team with a reduced crew size could increase the workload scores of operators. When a submarine is operating in conditions of high demand, having a reduced crew may present more issues as there is a potentially higher risk of work overload. Therefore, reduced crew sizes may threaten the overall safety of submarine operation and call into question the efficacy of removing members of the command team to minimise economic costs.

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