The effects of a circle room configuration on submarine command team workload

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ABSTRACT

The Command Team Experimental Test-Bed (ComTET) project aims to investigate the operation of contemporary and future submarine control rooms. Previous ComTET research has found that facilitating non-verbal communication between Sonar Operators (SOPS) and Target Motion Analysts (TMA) helped reduce a communications bottleneck and better manage their workload. The present study explores workload in a novel circular control room configuration which enables non-verbal communication between all operators. Participants completed low and high demand versions of Return to Periscope Depth (RTPD), In Shore Operations (INSO) and Dived Tracking (DT), six scenarios in total. After each scenario was completed the NASA-Task Load Index (NASA-TLX) was filled out. The present work looks at a subset of four teams from each configuration as a preliminary analysis to provide insight into the direction of trends in the data. Results show that perceived workload is affected by the configuration, with the circle layout producing slightly greater overall workload (except for DT and INSO high demand).

KEYWORDS

Workload, Command Team, Submarine

Introduction

Managing increasing volumes of data for submarine command teams will become more important as sensors become more advanced. It is likely that the increased amounts of data will in turn increase workload for operators as this data needs to be analysed and integrated into the tactical picture (Woods et al., 2002). Workload is defined as the perceived relationship between the mental processing and resources required by a task, and the individual's capability (Hart & Staveland, 1988). Operators must remain at a level of cognitive arousal that is not over stimulating, as this can lead to tasks taking longer to complete (Biondi et al., 2020), shedding secondary tasks (Roberts, Stanton & Fay, 2017), slower reaction times, reduced memory (Fox et al., 2007), not completing tasks in order (Hart & Staveland, 1988), lower task performance rates (Owens et al., 2018) and in extreme cases a failure to perform at all (Hart & Staveland, 1988). This is not just theoretical and operator overload has caused accidents to occur in the past, such as the collision between stern trawler Karen (B317) and a Royal Navy (RN) submarine in 2015 (Marine Accident Investigations Branch Report No. 20/2016, 2016).

Additionally previous research has found that there is a communication bottleneck in traditional submarine control rooms between the Sonar Controller (SOC) and the Operations Officer (OPSO), which affects the workload of the team (Roberts, Stanton & Fay, 2017). If this communication pathway becomes saturated or backlogged, it will prevent tasks from being completed in a suitable timeframe and could even lead to reduced task performance in cases where required information was not received (Stanton & Roberts, 2019a). Previous research investigated a co-location configuration which seated the Target Motion Analysis (TMA) and Sonar Operators (SOP) next to

each other, as traditionally some sonar information is passed through the SOC and the OPSO before reaching TMAs (Stanton & Roberts, 2019a). This change was effective at reducing the communication bottleneck by allowing significantly greater volumes of information to be communicated, which in turn increased task performance (Stanton & Roberts, 2019a). It was suggested that the co-location configuration could potentially increase the workload of the OPSO, as the sonar team were now located within the same room which generates more potential communication pathways (Stanton & Roberts, 2019b). However, it was found that the TMAs and SOPs favoured direct communication, which effectively reduced communication across the OPSO (Stanton & Roberts, 2019b).

A large portion of traditional control room communication is done aurally via radio (Stanton & Roberts, 2017). Research has found that face-to-face is the richest form of communication allowing for immediate feedback (Daft & Lengel, 1986), with facial expressions (Hwang & Matsumoto, 2015) and eye contact (Argyle & Dean, 1965; Bohannon et al., 2013) being powerful communication tools. In the high demand co-located scenarios, all operators compensated for the increased workload by communicating more. Therefore, implementing a configuration which enhances face-to-face communication could aid in workload management (Roberts et al., 2019; Stanton & Roberts, 2019a; Stanton & Roberts, 2019b). Additionally, submarine command teams are required to verbally confirm when they are ready to receive and the receipt of information, which could be contributing to workload and the communication bottleneck (Stanton & Roberts, 2017). By allowing operators to communicate face-to-face they can utilise non-verbal cues such as making eye contact when ready to receive and nodding to confirm information receipt (Cassell et al., 2001). In the co-location study, it was suggested the TMA and SOP operators were able to use Non-Verbal Communication (NVC) due to their co-location, which may have helped them manage their workload (Stanton & Roberts, 2019a). Additionally, non-verbal cues can reduce the number of interruptions that occur which would reduce the need to repeat information (Boyle et al., 1994). Therefore, the present study predicts that enabling face-to-face communication will help the command team to maintain the overall workload.

The results of the co-located study advised the Officer of the Watch (OOW) should remain in a central position in any future configurations (Roberts et al., 2019). Their role is to revise the generated tactical picture and commanding the team (Stanton & Roberts, 2017). In the co-location study, the OOW could not see all the operator's screens from their seat and was therefore required to verbally communicate information or physically walk around the control room (Roberts et al., 2019). Therefore, it is suggested that the OOW would benefit from being in a central location and being able to see all operators' screens (Roberts et al., 2019). However, having an outward facing configuration, that would allow for the OOW to view all operator screens, would not allow for face-to-face communication, therefore in the present study the OOW was positioned at the centre of an inwards facing circle and there were three large screen displays which showed key information from the team (see Figures 1a & 1b) (Stanton et al., 2021).

The current study compared the workload of the novel circular configuration to a baseline study with a traditional submarine control room layout (Stanton & Roberts, 2017). It provides a preliminary analysis of the trends in the data and looks at a sub set of four teams from each configuration. Workload is measured using NASA-TLX (Hart & Staveland, 1988).

Methods

Design

To allow for the best comparison, the study used the same methods as the Baseline study (Roberts, Stanton & Fay, 2017). A between subjects design was used. The independent variables were the configuration of the control room (2 levels: traditional layout or "Baseline" and the circle

configuration), the scenario type (3 levels: RTPD, INSO and DT), and the scenario demand (2 levels: High and Low). The dependant variable was the overall average score from NASA-TLX.

Participants

A team of nine currently operational submariners were recruited from the RN via voluntary sampling. All participants were male, with an age range of 25-46. Security regulations prevented the collection of some demographic information. The team was similar to that which was recruited for the baseline study; however, a different Lieutenant Commander and Commander were present. The study protocol received ethical approval from the University of Southampton Research Ethics Committee (Protocol No: 10099) and the Ministry of Defence Research Ethics Council (Protocol No: 551/MODREC/14).

Materials

The ComTET submarine control room simulator was designed to be representative of a currently operational RN submarine (Roberts et al., 2015). It was re-fitted into the circular configuration; however, the fundamental parts remained the same as the baseline. The redesign was based on previous research findings and was reviewed by several Subject Matter Experts from both the RN and industry partners (Stanton & Roberts, 2017). (See Figures 1a & 1b).

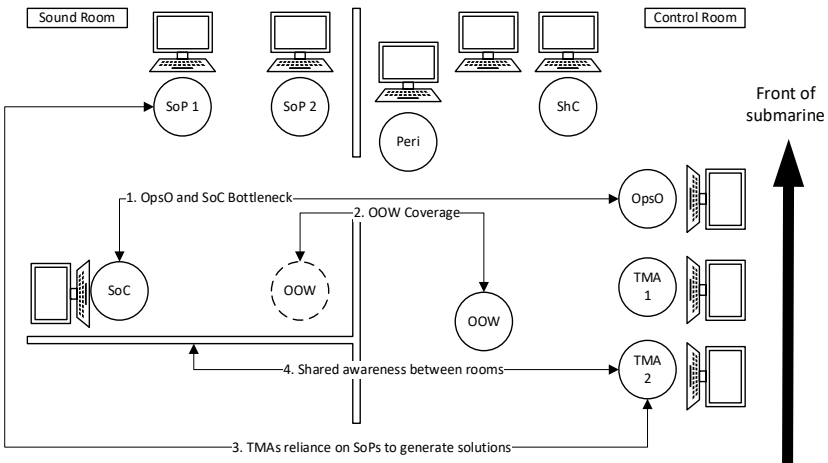

Figure 1a. Baseline Configuration

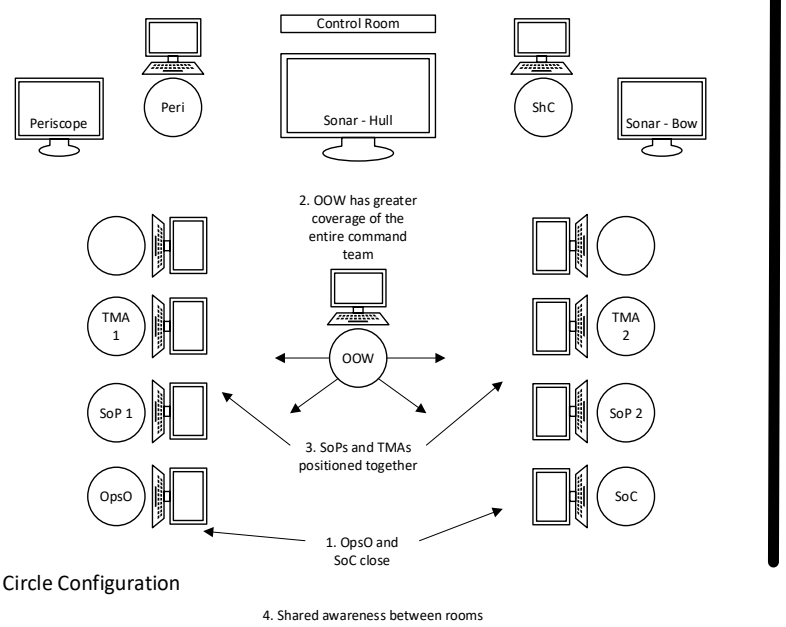

Figure 1b. Circle Configuration

NASA-TLX was used to measure subjective workload (Hart & Staveland, 1988). The NASA-TLX questionnaire is made up of 6 subscales: Mental Demand, Physical Demand, Temporal Demand, Performance, Effort and Frustration (Stanton et al., 2017, p.300). Each item is scored on an interval scale divided into 20 from low (1) to high (20) (Stanton et al., 2017, p.302).

Participants completed low and high demand versions of three different scenarios: RTPD, INSO and DT. For an outline of each scenario see Table 1. The order of tasks was counter balanced across participants. Each scenario took around 45 minutes to complete.

The participants took on one of several roles which each had their own workstations: Operations Officer (OPSO), Sonar Controller (SOC), two Sonar Operators (SOP), two Target Motion Analysts (TMA), Periscope (PERI), and Ship Control (SHC).

Table 1: Descriptions of the scenarios at different demand levels.

Scenario	Demand Level	Number and Type of Contacts	Description
Return to Periscope Depth (RTPD)	Low	4 - Fishing	The vessel must RTPD from deep to send intelligence home. All contacts must be ranged to find the optimum course. Scenario completed when periscope has marked all contacts.
	High	9 - Fishing 3 - Catamaran 1 - Biological	RTDP as quickly as possible due to severe submarine damage. Attempt to range all contacts to find the optimum course.
Inshore Operations (INSO)	Low	3 - Merchant 1 - Yacht 1 - Freighter	Navigate the vessel safely inshore to gather intelligence on a land-based target. Scenario completed when close enough to photograph the target building.
	High	2 - Merchant 1 - Powerboat 5 - Fishing	Identify and track a suspect contact inshore to gather intelligence on activities being carried out and the building they are operating from.
Dived Tracking (DT)	Low	3 - Fishing 1 - Sailboat 1 - Nimitz	Beginning at periscope depth the goal is to locate and tract a nearby priority contact (Nimitz warship). Scenario completed when all contacts have been ranged and the priority vessel is tracked.
	High	7 - Fishing 2 - Merchant 1 - Nimitz	Locate and track the nearby priority contact (Nimitz warship) after a near collision forces an emergency go deep procedure.

Procedure

Participants gave informed consent and were assigned stations based on their operational role in the RN. Participants had an hour of training to familiarise themselves with the simulator before beginning the experimental trials; most of the participants were present in the baseline study (apart from the Lieutenant Commander) and were therefore already familiar with the simulator software. A single trial was as follows: the OOW briefed the command team on the scenario, the tasks were completed. After each scenario, participants were asked to complete the NASA-TLX ratings and were then allowed a short break and provided with refreshments. Each scenario took around 45 minutes to complete and the NASA-TLX took a further 10 minutes. At the end of the testing day participants were given a full debrief and thanked for participating.

Results

Data analysis for the full data set is still underway, therefore this paper looks at a subset of four teams, to provide an indication of the direction of trends. This analysis uses the "raw-TLX" method where all measures are averaged to give an overall workload score (Hart, 2006). Full statistical analysis is planned to be completed once all the data has been processed.

NASA-TLX Scores

Both the baseline and circle configuration groups found that workload was greater in the high demand scenarios than in the low demand scenarios (Baseline configuration low demand: M=8.72, SD=5.38. Baseline configuration high demand: M=9.81, SD=5.06. Circle configuration low demand: M= 7.70, SD=4.85. Circle configuration high demand M= 9.90, SD=4.85). The condition with the highest workload for the Baseline configuration was DT High demand and for the Circle configuration it was INSO High demand.

When comparing the overall scores across demand levels the low demand scenarios had lower workload on average apart from DT in the circle configuration which showed marginal differences (see Table 2 for a breakdown of the scenario means).

When comparing the scores across configurations, in general the circle configuration appears to have greater workload than the baseline for all RTPD scenarios, INSO High demand and DT Low demand. INSO Low demand and DT High demand had lower workload in the circle configuration.

Table 2: NASA-TLX Means and Standard Deviations (rounded to two decimal places) broken down by configuration, scenario type and demand level.

Scenario Type	Demand Level	Baseline Configuration	Circle Configuration
RTPD	Low	8.05 ± 5.01	9.99 ± 7.28
	High	9.82 ± 5.91	10.06 ± 4.60
INSO	Low	7.43 ± 5.30	6.61 ± 5.23
	High	9.51 ± 4.79	10.10 ± 4.21
DT	Low	9.04 ± 5.72	9.79 ± 5.62
	High	10.11 ± 5.37	9.42 ± 5.63

Discussion

It was expected that the workload would be reduced in the circle configuration, as this layout has been found to improve communication within the submarine control room (Pope et al., 2018;

Roberts et al., 2019; Stanton & Roberts, 2019a; Stanton & Roberts, 2019b). However, the findings found that the workload was greater during the circle configuration (except for DT high and INSO low demand). The increased perceived workload could reflect the number of tasks completed by the command team. It is expected that more subtasks will be completed during high demand scenarios as there are more contacts which need to be assessed for tactical picture generation (Roberts et al., 2015). Studies have found that in the circle configuration teams were able to complete significantly more subtasks such as checking cuts, completing sonar merges, and refining solutions (Stanton et al., 2020; Roberts et al., 2021; Stanton & Roberts, 2018). All these subtasks help to shape and refine the tactical picture, therefore being able to complete these more frequently may help the tactical picture to remain more accurate (It is important to note that ComTET has yet to assess tactical picture accuracy; Roberts et al., 2021). The increased workload scores during the high demand RTPD and INSO scenarios in the circle configuration may simply reflect the command team's ability to complete more subtasks.

Both the baseline and circle configurations show the effects of the scenario demand, with low demand having lower workload scores than high demand. This reflects the greater number of contacts, and therefore greater workload, in the high demand scenarios (Stanton & Roberts, 2017). The effect of scenario type varies as each scenario has differing levels of contacts and involves different task prioritisation. The baseline configuration reports DT high as the greatest workload and INSO Low demand as the lowest whereas the circle configuration reports INSO high demand as the greatest, closely followed by RTPD high demand. The least workload in the circle configuration was again INSO low demand. High demand RTPD and DT have the most contacts out of all the scenarios, 13 and 10 total contacts respectively (see Table 1). Therefore, it is expected these scenarios would have a higher workload. Both configurations showed low demand INSO to have the smallest workload. During INSO the submarine usually operates at periscope depth and often the periscope is used to search for and range contacts (Stanton & Roberts, 2017). In a low demand INSO scenario the submarine is less likely to complete a duck and run manoeuvre, which requires more input from the rest of the command team (Roberts et al., 2015). Therefore, the workload may be the lowest for this condition because it was not spread evenly across the whole command team, with the PERI operator contributing the most (Roberts et al., 2015).

To conclude, the findings of this paper suggests that the circle configuration layout increases the overall perceived workload. However, these differences are marginal and further statistical analysis is needed to decide if these differences are significant. Results should be treated according to their limited statistical power, serving only as a preliminary insight.

References

Argyle, M., & Dean, J. (1965). Eye-contact, distance and affiliation. Sociometry, 28(3), pp.289–304.

Biondi, F. N., Cacanindin, A., Douglas, C., & Cort, J. (2020). Overloaded and at Work: Investigating the Effect of Cognitive Workload on Assembly Task Performance. Human Factors. https://doi.org/10.1177/0018720820929928

Bohannon, L. S. et al. (2013) 'Eye contact and video-mediated communication: A review', Displays, 34(2), pp.177–185. https://doi.org/10.1016/j.displa.2012.10.009

Boyle, E. A., Anderson, A. H., & Newlands, A. (1994). The effects of visibility on dialogue and performance in a cooperative problem solving task. Language and Speech, 37(1), pp.1–20. https://doi.org/10.1177/002383099403700101

Cassell, J., Bickmore, T., Campbell, L., Vilhjálmsson, H., & Yan, H. (2001). More than just a pretty face: Conversational protocols and the affordances of embodiment. Knowledge-Based Systems, 14(1–2), pp.55–64. https://doi.org/10.1016/S0950-7051(00)00102-7

Daft, R. L. and Lengel, R. H., 1986. Organizational information requirements, media richness and structural design. Management science, 32(5), pp.554-571. https://doi.org/10.1287/mnsc.32.5.554

Fox, J. R., Park, B. & Lang, A., 2007. When available resources become negative resources: The effects of cognitive overload on memory sensitivity and criterion bias. *Communication Research*, *34*(3), pp.277-296. https://doi.org/10.1177/0093650207300429

Hart, S. G. (2006). NASA-task load index (NASA-TLX); 20 years later. In *Proceedings of the human factors and ergonomics society annual meeting* (Vol. 50, No. 9, pp. 904-908). Sage CA: Los Angeles, CA: Sage publications. https://doi.org/10.1177/154193120605000909

Hart, S. G., & Staveland, L. E. (1988). Development of NASA-TLX (task load index): Results of empirical and theoretical research. In P. A. Hancock & Meshkati. Advances in Psychology, 52, pp.139-183. https://doi.org/10.1016/S0166-4115(08)62386-9

Hart, S. G., Pope, K. A., Banks, V. A., Roberts, A. P. and Stanton, (2021), Examining the effect of reduced crew sizes on submarine command team workload. CIEHF Ergonomics and Human Factors Conference. Accessed on [02/09/2021]. Retrieved from: https://publications.ergonomics.org.uk/uploads/01_39.-edited.pdf

Hwang, H. & Matsumoto, D. (2015) 'Evidence for the universality of facial expressions of emotion', in Mandal, M. K. and Awasthi, A. (eds) Understanding facial expressions in communication: Cross-cultural and multidisciplinary perspectives. New York, NY: Springer Science + Business Media, pp.41–56. https://doi.org/10.1007/978-81-322-1934-7_3

Marine Accident Investigation Branch, 2016. *Report on the investigation of the collision between the stern trawler Karen (B317) and a dived Royal Navy submarine in the Irish Sea on 15 April 2015*. Marine Accident Investigation Branch, Southampton, United Kingdom. Accessed [29/09/2021]. Retrieved from: https://www.gov.uk/maib-reports/collision-between-the-stern-trawler-karen-and-a-dived-royal-navy-submarine

Owens, J. M., Dingus, T. A., Guo, F., Fang, Y., Perez, M., & McClafferty, J. (2018). Crash risk of cell phone use while driving: A case- crossover analysis of naturalistic driving data. Accessed on [12/09/2021]. Retrieved from: https://aaafoundation.org/wp-content/uploads/2018/01/CellPhoneCrashRisk_FINAL.Pdf

Pope, K. A., Roberts, A. P. and Stanton, (2018). An assessment of workload in a simulated submarine control room. CIEHF Ergonomics and Human Factors Conference. Accessed on [02/09/2021]. Retrieved from: https://publications.ergonomics.org.uk/uploads/An-assessment-of-workload-in-a-simulated-submarine-control-room.pdf

Roberts, A. P. J., Stanton, N. A., & Fay, D. (2015). The command team experimental test-bed stage 1: design and build of a submarine command room simulator. Procedia Manufacturing, 3, pp.2800– 2807. https://doi.org/10.1016/j.promfg.2015.07.745

Roberts, A., Stanton, N. A., & Fay, D. (2017). The Command Team Experimental Test-Bed Phase Two: Assessing Cognitive Load and Situation Awareness in a Submarine Control Room. In Advances in Human Aspects of Transportation. Springer International Publishing. pp.427-43. https://doi.org/10.1007/978-3-319-41682-3_36

Roberts, A. P. J., Stanton, N. A., Fay, D., & Pope, K. A. (2019). The effects of team co-location and reduced crewing on team communication characteristics. Applied Ergonomics, 81, p.102875. https://doi.org/10.1016/j.apergo.2019.102875

Roberts, A. P., Stanton, N. A., Fay, D. and Pope, K. A., 2021. It's a circular argument: Examining how a novel configuration impacts information flow in submarine control rooms. *Applied Ergonomics*, *97*, p.103534. https://doi.org/10.1016/j.apergo.2021.103534

Stanton, N. A., & Roberts, A. P. J. (2017). Examining social, information, and task networks in submarine command and control. *IEEE Transactions on Human-Machine Systems*, *48*(3), pp.252–265. https://doi.org/10.1109/THMS.2017.2720659

Stanton, N. A., & Roberts, A. P. J. (2017). Examining social, information, and task networks in submarine command and control. *IEEE Transactions on Human-Machine Systems*, *48*(3), 252-265. https://doi.org/10.1109/THMS.2017.2720659

Stanton, N. A., & Roberts, A. P. J. (2019a). Better together? Investigating new control room configurations and reduced crew size in submarine command and control. *Ergonomics*, *63(3)*, pp.1-27. https://doi.org/10.1080/00140139.2019.1654137

Stanton, N. A., & Roberts, A. P. J. (2019b). Block off: an examination of new control room configurations and reduced crew sizes examining engineered production blocking. *Cognition, Technology & Work*. https://doi.org/10.1007/s10111-019-00542-x

Stanton, N. A., Roberts, A. P. J., & Fay, D. (2017). Up periscope: understanding submarine command and control teamwork during a simulated return to periscope depth. *Cognition, Technology & Work*, *19*(2–3), pp.399–417. https://doi.org/10.1007/s10111-017-0413-7

Stanton, N. A., Roberts, A. P., Pope, K. A. and Fay, D., (2020). Returning to periscope depth in a circular control room configuration. *Cognition, Technology & Work*, pp.1-22. https://doi.org/10.1007/s10111-020-00654-9

Stanton, N. A., Roberts, A. P. J., Pope, K. A., & Fay, D. (2021). The Quest for the Ring: A Case Study of a New Submarine Control Room Configuration. *Ergonomics*, Advance online publication, pp.1–23. https://doi.org/10.1080/00140139.2021.1961857

Stanton, N. A., Salmon, P. M., Rafferty, L. A., Walker, G. H., Baber, C. and Jenkins, D. P., (2017). *Human factors methods: a practical guide for engineering and design*. CRC Press. Ch 8, pp.300-309. https://doi.org/10.1201/9781315587394

Woods, D. D., E. S. Patterson, and E. M. Roth. 2002. “Can We Ever Escape from Data Overload? a Cognitive Systems Diagnosis.” Cognition, Technology & Work 4 (1): 22–36. https://doi.org/10.1007/s101110200002