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Returning to periscope depth in a circular control room configuration

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Abstract

Previous research has shown that co-location of operators dependent on each other for task-relevant information can relieve the previously identified bottleneck of information between the Sonar Control (SOC) and Operations Officer (OPSO) in submarine sound and control rooms. This research aimed to examine the impact of a novel inwards facing circular configuration on communications and tasks within a co-located control room. Ten teams participated in high and low demand Return to Periscope Depth scenarios in a simulated submarine control room. All communications between operators were recorded and compared with a baseline study of contemporary operation. The findings show that the novel circular configuration led to a reduction in communications, but an increase in information shared. Indicating that the teams had become more efficient at passing relevant information. Furthermore, teams were able to complete a greater number of tasks.

Keywords Submarine · Teamwork · Communications · Networks · Control room configuration

1 Introduction

1.1 Contemporary submarine control room design

Submarine command teams are characteristic of distributed teams due to their reliance on technology to communicate between the separate sound and control rooms (Cramton 2001; Hinds and Bailey 2003; Hamburger et al. 2011; Stanton et al. 2017). In contemporary submarines, Sonar Operators (SOPs) and Target Motion Analysis operators (TMAs) are reliant on the Sonar Controller (SOC) and the Operations Officer (OPSO), to pass information between the sound room and the control room (Roberts et al. 2017a, 2018; Stanton et al. 2017). Passive sonar is the key sensor used when operating at depth (Zarnich 1999; Kirschenbaum et al. 2014). In such scenarios, the SOPs are required to pass on information about contacts such as bearing, course, and speed (Stanton et al. 2017). The distributed nature of the command team means that information exchange is often incomplete or missing entirely (Hinds and Bailey 2003). In a baseline study of a contemporary submarine control room operations,

Neville A. Stanton n.stanton@soton.ac.uk Stanton et al. (2017) identified a bottleneck of information between the SOC and the OPSO; the two operators responsible for passing information between the sound and control rooms. Further issues that stem from the distributed nature of the command team include a failure to share uniquely held information (Hinds and Bailey 2003). In a submarine control room, the Officer of the Watch (OOW) is required to assimilate data from disparate sources to maintain safety and make tactical decisions (Dominguez et al. 2006; Roberts et al. 2017a). However, due to the distributed nature of the team and the lower status of the SOPs, critical information such as speed and course estimates may not be being shared in some circumstances, hindering completion of an accurate tactical picture (Hinds and Bailey 2003; Stanton et al. 2017).

While submarine command rooms represent a high state of evolution it does not mean they cannot be improved (Stanton 2014; Stanton and Roberts 2017). Technological advancements such as noise-cancelling headphones mean that the sound and control rooms are no longer required to be separate (Hamburger et al. 2011). A study by Stanton and Roberts (2020a) co-located the SOPs and TMAs in the control room, allowing the operators to communicate with each other about task-relevant information. This co-location configuration enabled greater volumes of communication and greater efficiency in the control room, reducing the previously identified bottleneck between the OPSO and the SOC (Stanton et al. 2017; Stanton and Roberts 2020a, b;

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Roberts et al. 2019). In this study, however, operators still faced the outwards of the control room, preventing face-toface communication that is traditionally associated with colocated teams (Hinds and Bailey 2003; Stanton and Roberts 2020a). Traditionally, the control room was required to be located at the top of the submarine due to the hull penetrating periscope (Stanton and Bessell 2014; Scott 2017). Therefore, operator consoles faced outwards to effectively utilise space (Stanton and Bessell 2014). However, these legacy constraints can now be overcome thanks to technological advancements. Optronic mast systems have removed the requirement for mast penetration through the hull, instead, an electronic cable is required (Scott 2017). This offers greater flexibility in submarine control room location and design, such that the control room could be moved to a wider part of the ship (Hamburger et al. 2011; Scott 2017; Stanton and Roberts 2020a, b). If the control room were to be moved, this would also facilitate incorporating the sound room into the control room (Hamburger et al. 2011). Furthermore, movement of the control room from the top deck to middeck may allow for different configurations of the control room (Hamburger et al. 2011). In the larger space permitted, it would be possible to arrange the operator consoles so that they face inwards in a circular configuration, facilitating face-to-face contact that is characteristic of co-located teams (Hamburger et al. 2011).

1.2 Circular control room configuration

From King Arthur's round table (Perkins 2003) to the London 2012 Olympic Stadium (Crockford et al. 2011) circular style physical arrangements have been bringing people together throughout history (Falout 2014). In an analysis of operation room layouts Hendy et al. (2000) concluded that inward-facing layouts were more efficient than an outward-facing layout. In a submarine control room, an inwards facing circular configuration would allow all operators to see each other, and placing the OOW in the centre would ensure they remain central to the command team (Roberts et al. 2019). Furthermore, in a circular configuration the "potential to be commanded" may be increased due to the OOW being able to view facial aspects of operators rather than the backs of their heads; a factor considered by Hendy et al. (2000) when examining operations room layouts. The improved visibility of all operators may facilitate greater coordination within the team, and as such communication would be aided by the addition of facial expressions, gestures, and other non-verbal cues (Hendy et al. 2000). Eye contact, a crucial element of communication, between operators would be permitted, promoting greater cooperation and more favourable attitudes (Argyle and Dean 1965; Wichman 1970; Gardin et al. 1973). The requirement for operators to verbally acknowledge receipt of information may be contributing to the bottleneck of information previously identified in contemporary control rooms (Roberts et al. 2017a, 2018; Stanton et al. 2017). In contemporary submarine control rooms, operators are not able to utilise non-verbal cues such as nodding to indicate understanding (Clark and Brennan 1991). As such operators must verbally confirm the information they receive from other operators, potentially increasing communications in the control room (Cassell et al. 2001), although this does mean that the transmitter of the information knows that it have been received correctly. When operators are unable to see visual cues they interrupt speech more frequently, further inflating communications between operators (Boyle et al. 1994). In a circular configuration, operators will be able to supplement their own communications with non-verbal cues, potentially reducing the number of communications required (McNeill 1992).

With the OOW situated in the centre of the circular configuration not only will they be able to monitor what operators are working on (if slave monitors on the reverse of the workstation are provided), they can also monitor operator workload. From the centre, the OOW may be able to deduce that operators are under high workload from eye movements and facial expressions (Dinges et al. 2005; Ahlstrom and Friedman-Berg 2006; Halverson et al. 2012). High workload is indicated by shorter blink duration and larger mean pupil diameter (Ahlstrom and Friedman-Berg 2006). Furthermore, negative facial expressions (including eyebrow and mouth movements) exhibited by operators may also aid the OOW in determining if an operator is experiencing high workload (Dinges et al. 2005). Submarines of the future are likely to include more advanced sensors and instruments such as Unmanned Underwater Vehicles (UUVs) (Hewish 2002; Stanton and Roberts 2020a). The greater volume of data gathered from these new and improved sensors will be handled by a crew size that is likely to be similar to current requirements or potentially reduced (Masakowski and Hardinge 2000; Roberts et al. 2017b; Fay et al. 2019). Therefore, it is critical that operator workload is maintained at a suitable level for optimal performance (Masakowski 2000). If the OOW is able to monitor operator workload from the centre of the control room they will better be able to decide where additional resource is required and allocate as necessary.

In the current work, the impact of a novel circular control room configuration upon submarine command team performance was examined during high and low demand Return To Periscope Depth (RTPD) scenarios. During a RTPD the command team must use passive sonar to detect and designate all contacts and create a tactical picture before safely returning to periscope depth (Zarnich 1999; Kirschenbaum et al. 2014; Stanton et al. 2017). The current work builds upon previous studies that examined current ways of working during RTPD scenarios (Stanton et al. 2017) and a co-located configuration with different crew sizes (Stanton and Roberts 2020a, b). The aim of the current work is to evaluate the circle configuration and secondly to compare the results to the baseline comparator (Stanton et al. 2017).

2 Methods

2.1 Participants

A total of 10 teams of eight and 10 teams of seven (150 participants total across both studies) were recruited opportunistically from a variety of backgrounds, primarily including undergraduate students and graduate recruits from defence companies and organisations. Ideally, all of the participants in the study would be serving submariners but, as noted in previous research, they are not readily available (Stanton 2020b). Also, teamwork studies of this nature rely upon quite large numbers of participants. Overall, a total of 128 males and 22 females participated with an age range of 18-55 (Mean = 27.19, SD = 6.56) Participants were randomly allocated to one condition based on time of recruitment (baseline studies were run first). In the baseline study, a total of 71 males and 9 females participated with an age range of 18-55 (Mean = 26.83, SD = 8.69) and in the experimental (circle configuration) condition a total of 57 males and 13 females participated with an age range of 21-44 (Mean = 27.54, SD = 4.42). Two teams of participants (one per condition) were submariners from the British Royal Navy (RN). The study protocol received ethical approval from the University of Southampton Research Ethics Committee (Protocol No: 10099) and MODREC (Protocol No: 551/MODREC/14).

2.2 Equipment: the submarine control room simulator

A submarine control room simulator, representative of a currently operational RN submarine, with nine networked workstations was built for testing (for full description see Roberts et al. (2015), see Fig. 1a for configuration). The networked workstations included an OOW station, an OPSO station, a SOC station, two SOP stations, two TMA stations, a Periscope station (PERI) and a Ship Control station (SHC). In all studies, the role of the OOW was assumed by an experimenter to guide the scenarios tactically. In the circle condition, the role of SHC was also played by an experimenter. Based upon the findings of baseline studies and input from Human Factors Subject Matter Experts (SMEs) and Submarine operation SMEs the configuration of the control room was changed for the circle condition (see Fig. 1b). All other aspects

(e.g. interfaces, scenarios, roles etc.) remained exactly the same in the circle condition to avoid experimental confounds.

Two RTPD scenarios were designed with SME input and programmed in the simulation engine Dangerous Waters (DW) (see Table 1). DW, a software package developed by Sonalysts, featured networked workstations for each of the roles. Contact movements were predetermined to be consistent across all teams and each scenario lasted approximately 45 min. The simulator was equipped with a comprehensive recording suite, including web cameras and ambient microphones, which allowed the recording of all communications that occurred between command team members.

2.3 Study design

The independent variables were scenario demand (within subjects), operator role (between subjects—social network), information type (within subjects—information network) and task type (within subjects—task network). Scenario demand was manipulated by contact behaviour (e.g. speed and course changes vs. steady), the number of contacts detectable in the scenario, and area of operation (see Table 1). The design of scenarios was informed by SMEs to be representative of real high and low demand RTPD operations. The dependent variables were static adjacency matrices (social, information and task) derived from the communications that took place between operators within the command team.

When examining the circle configuration independently, the study employed a 2×9 mixed design (social networks), a 2×14 repeated measures design (information networks) and a 2×12 repeated measures design (task networks). When comparing the baseline configuration to the circle configuration the design was extended, employing a $2 \times 2 \times 9$ mixed design (social networks), a $2 \times 2 \times 14$ mixed design (information networks) and a $2 \times 2 \times 12$ repeated measures design (task networks). The study design remained largely constant between the baseline study and the circle configuration study, including the dependent variables. The comparison of the two configurations was between subjects.

2.4 Procedure

The procedure was identical for the baseline and circle conditions. Participants attended the submarine simulator for two full days (8 a.m.–5 p.m.). On the first day, informed consent was attained, and a simulator induction was completed. After this, team roles were randomly assigned. The rest of the morning was spent watching a set of general submarine control room operation tutorials, whilst the afternoon was spent watching workstation specific tutorials and practicing tasks both individually and as a functional command **Fig. 1** Presentation of control room configuration used during baseline and circle configuration. The numbered points highlight the key issues revealed by the baseline studies and how these have been addressed in the circle configuration



4. Shared awareness between rooms

Table 1 Description of scen	arios
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Demand	No. Contacts	Mission
Low	4—Fishing	RTPD from deep to send intelligence home, large temporal window of opportunity. All contacts held must be ranged to find optimum course for RTPD. Scenario complete once periscope has marked all contacts
High	9—Fishing 3—Catamaran 1—Biological	RTPD as quickly as possible due to submarine damage. Attempt to range all contacts to find optimum RTPD course

Table 2 Description of tutorial training package		
Tutorial	Description	Purpose
Submarine Command	Introduction to the submarine simulator, the operator roles, the different sensors on board a submarine and the command structure within a submarine command team	Develop basic understanding of what a submarine command team does, what type of data is received, what the operator roles are
Introduction to bearing, speed, course, and range	Describing the basics of bearing, speed, range, and course in relation to own submarine and to contacts that might be surrounding the subma- rine. Describing passive sonar and how information concerning speed can be derived from analysis of sound	Develop an understanding that using passive sonar to create a tacti- cal picture requires the interpretation of ambiguous information. Understanding that the only definite information is the bearing at which contacts are heard and that acoustic signature processing can provide 'estimates' of speed
Military communication protocol	Detailing how military personnel are required to communicate with each other. A particular focus on clarity, conciseness, and not inter- rupting communication flows. The structure of the command team was also outlined	It was important to examine command team functionality with a level of fidelity that was comparable to operational procedures. The communication protocol in the military is clearly defined, it was important for operators to pass information in a manner comparable to operational teams
Anagram communication game (3 game trials)	This required participants to solve anagrams (analogous to processing data), then pass the words around the command team in a structured fashion (using standard verbal protocol) and then linking up the words to create a sentence (analogous to creation of a tactical picture)	This brought together the morning training session. It allowed participants to understand that they may all be completing dif- ferent tasks and contributing different pieces of information to facilitate the generation of an overall tactical picture. It allowed participants to practice operating as a command team without the complexities of the domain
Workstation tutorial (Sonar, TMA, Periscope and SHC)	A complete description of all workstation interfaces. What the funda- mental task requirements of each operator in the command team are and how they should interact with the interfaces to complete their specific duties within the command team	To develop an understanding of the particular tasks completed by each individual within the command team. This tutorial was completed individually with a focus on manipulating the interface for procedural task completion. Examples include how to spot a contact on sonar, how to listen to a contact, and how to designate a track ID on sonar
Practice workstation free play	Workstation specific training scenarios were developed to encapsulate all tasks participants would encounter. Participants completed sce- narios individually, with the rest of the command team 'auto crewed'. Experimenters answered any questions and guided participants through the completion of tasks they were unsure of	The purpose of this part of the training was to allow participants to complete all of the tasks that they would be expected to complete in the command team, without command team pressures. Participants could speed up time which allowed them to work at their own pace. Participants could also restart scenarios multiple times, allowing a focus on the tasks and procedures they felt needed the most attention
Command team tutorial	A detailed description of how the tasks completed by each individual operator (and the information derived) should be shared across the command team to facilitate the generation of a complete tactical picture	This part of the tutorial brings together the communication game, which taught participants the command structure and communi- cation protocol. Instead of using anagrams as data, participants were now made aware of the tasks and data they were responsible for and which members of the command team need this informa- tion to generate a tactical picture
Practice RTPD scenario completion	Participants completed shortened versions of the 2 scenarios (RTPD) that they would be expected to complete during testing. The scenarios were completed at least twice. Participants were given guidance from the experimenters concerning how the tasks completed at individual workstations feed into the global aims of the command team	At this point participants were accomplished at completing the procedures and tasks at their own workstations. The final training session pulled together everything that had been learnt throughout the day. This included completing tasks at their workstation, passing relevant output (data) to members of the command team

team (see Table 2 for a full description of tutorials). Regular breaks and refreshments were provided between tutorials, which each lasted approximately 45 min. Questions about tasks and operation of workstations as well as the communications protocol were encouraged.

The testing day (second day) started with a refresher training scenario as a functional command team. Performance was monitored by experimenters to ensure all tasks were being completed correctly in line with set criteria provided by SMEs (e.g., steering the submarine safely to relevant courses and depths, adequately detecting surrounding vessels, gaining solutions concerning surrounding vessels, and developing the tactical picture). Following the refresher training, the first scenario was begun-at which point all recording devices were started and a verbal time stamp was read aloud for synchronization purposes. The scenarios began with an OOW briefing outlining the mission objectives (see Table 1). The end of the scenario was called once the mission objective had been achieved. Each team completed both scenarios, occupying the same positions in the command team. To reduce order effects scenario presentation was counterbalanced across the 20 teams. Participants were provided with a short break between scenarios. At the end of the final scenario, participants were provided with a full debrief and thanked for participating.

2.5 Data analysis

A new shortened version of Event Analysis for Systemic Teamwork (EAST) (Stanton et al. 2008, 2019) was used for data analysis. EAST examines complex sociotechnical systems using a network approach. This method has been presented in a previous study to model submarine command and control (Stanton 2014) and was used in the baseline study (Stanton et al. 2017; Stanton and Roberts 2020a). The framework has also been applied in other domains such as air traffic control (Walker et al. 2010), aviation (Stewart et al. 2008), emergency services (Houghton et al. 2006), road safety (Salmon et al. 2014), and military risk assessment (Stanton and Harvey 2016). EAST facilitates an understanding of the processes undertaken by a submarine command team having completed an RTPD, utilising a network approach to understand how people, technology, information, and tasks were connected. Social networks analyse communications taking place between 'agents' in the system. Information networks describe the information nodes or 'pieces' that different agents in the system use and communicate during task performance. Finally, task networks describe the relationships between tasks, their sequence and interdependences.

Social, information, and task networks were generated from video and microphone recordings. Leximancer software (version 2.1—a software program for identifying concepts in text documents) was used to determine the nodes in the information networks. The top 14 information elements (according to frequency count) were included in the statistical analysis, based on the identification of the most important aspects of the task of returning to periscope depth identified in previous studies (Stanton and Roberts 2017, 2020a, b). AGNA software (version 2.1.1-a software program for computing the Social Network metrics) was used to compute whole network metrics (e.g. density, diameter and cohesion) and nodal metrics (e.g. sociometric status and centrality of each node) for all networks (see Table 3 for definitions of all metrics). Data from the novice and expert submariners were combined into one set as previous research has shown that there were quantitative rather than qualitative differences in the activities; expert submarines were able to perform more interactions and complete more tasks than their novice counterparts but they did not undertake fundamentally different activities (Stanton, 2020b).

Data analysis was completed in two stages. Firstly, the circle configuration was examined independently. Dependent t tests were conducted to examine the effect of scenario demand on global network metrics (for social and information networks). Differences in the frequency of task completion between scenarios of high and low demand were examined with 2×12 (demand \times task nodes) repeated measures Analyses of Variances (ANOVAs). To examine the effect of scenario demand and operator role on social node metrics 2×9 (demand \times operators) mixed ANOVAs were conducted. To examine the effect of scenario demand and operator role on social node metrics 2×14 (demand \times information nodes) repeated measures ANOVAs were conducted. In the interests of completeness, the statistical analysis of the baseline tests were reported in the tables, however, the results were not discussed in more detail as they are reported in the baseline studies and are outside of the scope of the current work. All other significant main effects were examined by conducting post hoc pairwise comparisons. To account for multiple comparisons the Bonferroni correction method was used $(\alpha = 0.05$ /number of comparisons).

In the second stage of analysis, a comparison of the circle to the baseline configuration was examined. For social and information networks 2×2 (configuration × demand) mixed ANOVAs were conducted to examine the effect of configuration and scenario demand on global network metrics. For social node metrics, to examine the effect of configuration, scenario demand, and operator role $2 \times 2 \times 9$ (manipulation × demand × operators) mixed ANOVAs were conducted. For information node metrics, $2 \times 2 \times 14$ (manipulation × demand × information nodes) mixed ANOVAs were conducted to examine the effect of configuration and scenario demand. $2 \times 2 \times 12$ (manipulation × demand × task nodes) repeated measures ANOVAs were conducted to

examine differences in the frequency of task completion based upon configuration and demand. When reporting the results of the configurations comparison main effects of demand were not reported, instead the interactions between demand and manipulation were focused upon, as this was the primary interest of the current work. All statistical analysis was conducted using IBM SPSS v21.

3 Results

3.1 Social network analysis

In the circle condition, the average frequency of communications between operators in the command team varied depending on command team role and scenario demand (see Fig. 2—key nodes highlighted in black). OPSO had the largest volume of emissions and receptions of all operators, although OOW and TMA1 also had a large number of emissions and receptions, particularly in the high demand scenarios. The overall composition of high and low demand networks is similar, however, the volume of interactions between operators increased during the high demand circle RTPD scenarios.

3.1.1 Whole network metrics

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In the circle configuration the total interactions (t(9) = 12.18, p < 0.05, r = 0.97) statistically significantly increased in the high demand circle condition. The total number of edges (F(1, 18) = 17.85, p < 0.05, $\dot{\eta}_p^2 = 0.50$), density (F(1, 18) = 17.72, p < 0.05, $\dot{\eta}_p^2 = 0.50$), cohesion (F(1, 18) = 5.80, p < 0.05, $\dot{\eta}_p^2 = 0.24$) and total interactions (F(1, 18) = 12.18, p < 0.05, $\dot{\eta}_p^2 = 0.51$) of the entire networks were statistically significantly affected by configuration type. This indicates

 Table 3 Definitions of global network metrics and node metrics

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that the structure of the networks fundamentally changed as a result of the new configuration, whilst the new configuration differentially impacted upon network structured based upon scenario demand (see Table 4).

3.1.2 Nodal metrics

3.1.2.1 Emissions In the circle configuration the total emissions of each node were statistically significantly affected by scenario demand ($F(1, 81) = 434.98, p < 0.01, \dot{\eta}_p^2 = 0.84$) and operator role ($F(8, 81) = 50.93, p < 0.01, \dot{\eta}_p^2 = 0.83$). The interaction of scenario demand and role also statistically significantly affected total node emissions (F (8, $(81) = 24.11, p < 0.01, \dot{\eta}_{p}^{2} = 0.70)$. When examining the effect of scenario demand, post hoc analysis revealed that overall, emissions were statistically significantly higher (p < 0.05) in the high demand RTPD condition than the low demand condition. All operators except PERI and SHC had statistically (p < 0.05) higher emissions in the high demand condition than the low demand condition. When examining the effect of role post hoc analysis revealed that OPSO had statistically significantly higher (p < 0.05) emissions than all other operators (see Table 5; Fig. 2). OOW and SOC had statistically significantly (p < 0.05) more emissions than all other operators except TMA1 and TMA2 with whom no significant difference was observed. PERI and SHC had statistically significantly (p < 0.05) less emissions than all operators. When examining the interaction between demand and role, post hoc analysis revealed that OOW had statistically significantly (p < 0.05) more emissions than SOC, SOP1, SOP2, TMA1, and TMA2 in the low demand condition but not in the high demand condition. OPSO had statistically significantly (p < 0.05) more emissions than OOW in the high demand condition but not in the low demand condition. SOP1 and SOP2 had statistically significantly (p < 0.05)

*This is not the same definition used in the teamwork literature on cohesion, which defines team cohesion as a multidimensional concept that includes (but is not limited to) a bonding and closeness between team members and a loyalty to the team (Salas et al. 2015). This may, or may not, include reciprocal communication connections





higher emissions than SHC and PERI in the high demand condition but no significant differences were observed in the low demand condition.

The total emissions of each node were statistically significantly affected by configuration type (*F* (1, 162)=73.20, p < 0.01, $\dot{\eta}_p^2 = 0.31$). The interaction of configuration type and role statistically significantly affected total emissions (*F* (8, 162)=10.42, p < 0.01, $\eta_p^2 = 0.34$). The interaction of configuration type, role, and demand did not statistically significantly affect emissions (*F* (8, 162)=0.74, p > 0.05). Further analysis revealed emissions were statistically significantly (p < 0.05) lower in the circle configuration compared

to baseline. Post hoc analysis revealed all operators except TMA1 and TMA2 had statistically significantly (p < 0.05) less emissions in the circle configuration than baseline.

3.1.2.2 Receptions In the circle configuration the total receptions of each node were statistically significantly affected by scenario demand (F(1, 81) = 482.27, p < 0.01, $\dot{\eta}_p^2 = 0.86$) and operator role (F (8, 81)=54.61, p<0.01, $\eta_p^2 = 0.84$). The interaction of scenario demand and role also statistically significantly affected total node receptions (F $(8, 81) = 31.61, p < 0.01, \dot{\eta}_p^2 = 0.76)$. When examining the effect of scenario demand, post hoc analysis revealed that, overall, receptions were statistically significantly higher (p < 0.05) in the high demand RTPD condition than the low demand condition. All operators except PERI and SHC had statistically (p < 0.05) higher receptions in the high demand condition than the low demand condition. When examining the effect of role post hoc analysis revealed that OPSO had statistically significantly higher (p < 0.05) receptions than all other operators (see Table 5; Fig. 2). SOC had statistically significantly (p < 0.05) more receptions than all other operators except TMA1 and TMA2 with whom no significant difference was observed. PERI and SHC had statistically significantly (p < 0.05) less receptions than all operators. When examining the interaction between demand and role post hoc analysis revealed that SOP1 and SOP2 had statistically significantly (p < 0.05) higher receptions than SHC and PERI in the high demand condition but no significant differences were observed in the low demand condition.

The total receptions of each node were statistically significantly affected by configuration type (F(1, 162) = 81.46, p < 0.01, $\hat{\eta}_p^2 = 0.34$). The interaction of configuration type and role statistically significantly affected total receptions (F(8, 162) = 10.11, p < 0.05, $\hat{\eta}_p^2 = 0.33$). The interaction of configuration type, role and demand did not statistically significantly affect receptions (F(8, 162) = 0.85, p > 0.05). Further analysis revealed receptions were statistically significantly (p < 0.05) lower in the circle configuration compared to baseline. Post hoc analysis revealed all operators except, TMA1, TMA2, SHC, and PERI had SOC had statistically significantly (p < 0.05) less receptions in the circle configuration compared to baseline.

3.1.2.3 Sociometric status In the circle configuration the sociometric status of each node was significantly affected by scenario demand ($F(1, 81) = 491.13, p < 0.01, \dot{\eta}_p^2 = 0.86$) and operator role (F (8, 81)=54.72, p < 0.01, $\eta_n^2 = 0.84$). The interaction of scenario demand and role also statistically significantly affected sociometric status (F(8, 81) = 29.52, p < 0.01, $\eta_p^2 = 0.75$). When examining the effect of scenario demand, post hoc analysis revealed overall, sociometric status was statistically significantly higher (p < 0.05) in the higher demand RTPD condition than the low demand condition. All operators except PERI and SHC had statistically significantly higher sociometric status in the high demand condition than the low demand condition. When examining the effect of operator role post hoc analysis revealed OPSO had statistically significantly (p < 0.05) higher sociometric status than all other operators. OOW and SOC had statistically significantly (p < 0.05) higher sociometric status than all other operators, except TMA1 and TMA2, with who no significant differences were observed. PERI and SHC had statistically significantly (p < 0.05) lower sociometric status than all other operators. When examining the interaction of demand and role post hoc analysis revealed SOC had statistically significantly (p < 0.05) higher sociometric status than SOP1 and SOP2 in the high demand condition but no significant difference was observed in the low demand condition.

The sociometric status of each node was statistically significantly affected by configuration type (F(1, 162) = 82.73, p < 0.05, $\hat{\eta}_p^2 = 0.34$) and the interaction of configuration type and role (F(8, 162) = 10.96, p < 0.01, $\hat{\eta}_p^2 = 0.35$). The interaction of configuration type, role and demand, did not significantly affect sociometric status (F(8, 162) = 0.72, p > 0.05). Further analysis revealed sociometric status was statistically significantly (p < 0.05) lower in the circle configuration compared to baseline. Post hoc analysis revealed OOW, OPSO, and SOC had statistically significantly (p < 0.05) lower

 Table 4
 Social network metrics for whole network RTPD baseline and circle configuration

	RTPD				Effect of Demand (t	Effect
	Baseline configurati	on	Circle configuration	on	Value) Circle configura- tion only	of Con- figuration (F
Lo	Low	High	Low	High		value)
Nodes	9	9	9	9	NA	NA
Edges	36.80 ± 3.01	36.50 ± 4.93	30.90 ± 3.41	32.70 ± 2.54	1.48	17.85***
Density	0.51 ± 0.04	0.51 ± 0.07	0.42 ± 0.06	0.45 ± 0.04	1.77	17.72***
Cohesion	0.34 ± 0.03	0.35 ± 0.03	0.36 ± 0.04	0.39 ± 0.04	1.43	5.80*
Diameter	3.00 ± 0.00	2.80 ± 0.42	3.00 ± 0.00	3.00 ± 0.00	0.00	2.25
Total Interactions	663.80 ± 206.32	816.10 ± 221.10	314.30 ± 47.28	638.80 ± 95.13	12.18***	18.89***

		F							
1	2	Emission				Keception			
		Baseline		Circle		Baseline		Circle	
		Low	High	Low	High	Low	High	Low	High
00W 1	10	111.2 ± 32.4	44 117±45.6	59.1 ± 7.33	87.2 ± 22.22	83.2 ± 30.5	94.5 ± 40.46	39 ± 15.74	57.3±23.87
OPSO 1	10	158.2 ± 55.3	27 204.2 \pm 52.97	81.5 ± 18.65	155.4 ± 30.45	161.7 ± 43.21	204.7 ± 49.82	80.2 ± 14.43	159.3 ± 32.03
SOC 1	10	141 ± 46.39	193.2 ± 54.35	35.2 ± 9.22	105.2 ± 27.87	143.8 ± 42.81	191.8 ± 50.93	38.5 ± 6.52	113 ± 23.11
SOP1 1	10	59.2 ± 34.9	8 64.5±35.02	17.3 ± 6.04	58.5 ± 15.31	55.2 ± 34.14	72.9 ± 43.04	21.6 ± 6.5	62 ± 16.28
SOP2 1	10	50.8 ± 25.2	5 72.1±39.64	20.6 ± 11.64	54.6 ± 18.57	58.1 ± 29.8	71.1 ± 36.68	24 ± 12.95	57.8 ± 20.57
TMA1 1	10	36.9 ± 16.6	61.8 ± 23.19	35 ± 12.36	71.7 ± 24.6	52.7 ± 20.5	70.8 ± 18.82	39.8 ± 12.61	76.4 ± 17.95
TMA2 1	10	49.5 ± 17.8	$3 58.1 \pm 20.18$	39.3 ± 15.62	78.5 ± 22.63	58.3 ± 19.99	68.4 ± 28.76	42.4 ± 13.13	82.1 ± 16.68
PERI 1	10	33.7 ± 9.19	25.8 ± 17.19	15.3 ± 4.79	16 ± 5.4	26.7 ± 7.32	20.9 ± 14.56	15.9 ± 4.48	16.9 ± 3.84
SHC 1	10	23.3 ± 13.5	9 19.4 ± 10.15	11 ± 2.67	11.7 ± 2.79	24.1 ± 9.89	21 ± 7.72	12.9 ± 2.42	14 ± 2.36
Effect of Demand M1 (f Value)		19.94***		434.98***		21.49***		482.27***	
Effect of Role M1 (f Value)		40.41^{***}		50.93^{***}		42.87***		54.61^{***}	
Demand*Role M1 (f Value)		3.43***		24.11^{***}		2.77***		31.61^{***}	
Effect of Configuration (f Value)		73.20***		81.46***		82.73***		0.10	
Effect of Configuration*Role		10.42^{***}		10.11^{***}		10.96^{***}		33.87***	
Effect of		0.74		0.86		0.72		0.87	
	Ν	Sociometric				Centrality			
		Baseline		Circle		Baseline		Circle	
		Low	High	Low	High	Low	High	Low	High
MOO	10	24.3±7.46	26.44 ± 10.72	12.26 ± 2.79	18.06 ± 5.68	5.61 ± 0.35	5.77 ± 0.35	6.05 ± 0.27	5.98 ± 0.24
OPSO	10	39.99 ± 11.14	51.11 ± 12.52	20.21 ± 4.03	39.34 ± 7.65	5.4 ± 0.3	5.31 ± 0.24	5.46 ± 0.26	5.33 ± 0.3
SOC	10	35.6 ± 10.99	48.13 ± 12.91	9.21 ± 1.91	27.28 ± 6.22	5.78 ± 0.5	5.68 ± 0.22	5.09 ± 0.32	5.17 ± 0.49
SOPI	10	14.3 ± 7.58	17.18 ± 9.65	4.86 ± 1.5	15.06 ± 3.79	4.12 ± 0.34	4.12 ± 0.14	4.18 ± 0.29	4.32 ± 0.3
SOP2	10	13.61 ± 6.8	17.9 ± 9.49	5.58 ± 3.05	14.05 ± 4.84	4.02 ± 0.21	4.11 ± 0.19	4.25 ± 0.21	4.27 ± 0.23
TMA1	10	11.2 ± 4.46	16.58 ± 4.81	9.35 ± 3.09	18.51 ± 5.16	3.91 ± 0.25	3.88 ± 0.15	4.45 ± 0.4	4.57 ± 0.38
TMA2	10	13.48 ± 4.58	15.82 ± 5.79	10.21 ± 3.42	20.08 ± 4.7	3.86 ± 0.11	4.01 ± 0.31	4.6 ± 0.27	4.62 ± 0.2
PERI	10	7.55 ± 1.71	5.84 ± 3.85	3.9 ± 1.07	4.11 ± 1.07	4.94 ± 0.47	5.07 ± 0.7	3.99 ± 0.19	3.89 ± 0.09
SHC	10	5.93 ± 2.87	5.05 ± 2.17	2.99 ± 0.62	3.21 ± 0.63	4.05 ± 0.31	3.79 ± 0.12	3.55 ± 0.15	3.48 ± 0.1
Effect of Demand M1 (f Value)		22.86***		491.13^{***}		0.01		0.001	
Effect of Role M1 (f Value)		44.29***		54.72***		39.41***		111.28^{***}	
Demand*Role M1 (f Value)		3.35***		29.52***		0.88		1.01	



Table 5 (continued)

3.1.2.4 Centrality The centrality of each node was not statistically significantly affected by scenario demand (*F* (1, 81)=0.10, p>0.05) but was significantly affected by operator role (*F* (8, 81)=111.28, p<0.01, $\hat{\eta}_p^2$ =0.92), although no significant interaction between scenario demand and role (*F* (8, 81)=1.02, p>0.05) was observed. When examining the effect of role post hoc analysis revealed OOW had statistically significantly (p<0.05) higher centrality than all operators. OPSO and SOC had statistically significantly higher centrality than all operators (except OOW). SHC had statistically significantly (p<0.05) lower centrality than all other operators.

The centrality of each node was not statistically significantly affected by configuration type (F(1, 162) = 0.10, p > 0.05) or the interaction of configuration type, role and demand (F(8, 162) = 0.87, p > 0.05). The interaction of configuration type and role statistically significantly affected sociometric status (F(8, 162) = 33.87, p < 0.01, $\eta_p^2 = 0.63$). Post hoc analysis revealed OOW and SOC had statistically significantly (p < 0.05) higher centrality in the circle configuration than in baseline. TMA1, TMA2, and PERI had statistically significantly (p < 0.05) lower centrality in the circle configuration compared to baseline.

3.2 Information network analysis

In the circle configuration the structure of the information networks is relatively consistent in both high and low demand RTPD scenarios with 'contact', 'bearing' and 'course' the most connected information pieces (see Fig. 3). The volume of emissions from most information elements appeared to increase in the high demand RTPD scenarios although differences in relationships can be observed.

3.2.1 Whole network metrics

In the circle configuration statistically significantly more emissions (t (9) = 4.68, p < 0.05, r = 0.84), nodes (t (9) = 6.81, p < 0.05, r = 0.92) and edges (t (9) = 4.69, p < 0.05, r = 0.84) in the high demand condition compared to low demand (see Table 6), indicating that the overall structure of information varied based upon scenario demand. Configuration statistically significantly affected the number of edges (F (1, 18) = 4.69, p < 0.01, $\dot{\eta}_p^2 = 0.21$), diameter (F(1, 18) = 5.49, p < 0.01, $\dot{\eta}_p^2 = 0.23$), and network density (F(1, 18) = 25.91, p < 0.01, $\dot{\eta}_p^2 = 0.59$). The number of edges and network density was statistically significantly (p < 0.05) lower in the circle configuration compared to baseline but the diameter of the networks was higher. Indicating that the a



Fig. 3 Information networks RTPD circle configuration high and low demand

Table 6 Information network Metrics for entire network RTPD circle and baseline

	Baseline		Circle	Circle		Effect of	Demand*configuration
	Low	High	Low	High	Demand (t Value)	configu- ration (F value)	value
Nodes	45.60 ± 5.10	44.40±6.46	40.1 ± 5.2	47.5±3.54	6.81***	0.44	8.92***
Edges	702.10 ± 330.28	644.80 ± 357.54	372.4 ± 100.4	529.6 ± 123.23	4.69***	4.69*	4.51*
Density	0.49 ± 0.15	0.49 ± 0.19	0.24 ± 0.03	0.24 ± 0.04	0.31	25.91***	0.00
Diameter	3.30 ± 0.82	3.5 ± 0.53	4 ± 0.82	4 ± 0.67	0.00	5.49*	0.27
Total Emissions	2412.10 ± 1424.21	2898.90 ± 2620.68	1209.6 ± 384.77	1919.6 ± 509.44	4.68***	3.16 ^t	0.14

circle configuration changed the structure of the information networks.

3.2.2 Nodal metrics

3.2.2.1 Emissions In the circle configuration the total emissions of each node were statistically significantly affected by scenario demand (*F* (1, 126)=171.73, p < 0.01, $\dot{\eta}_p^2 = 0.58$) and concept type (*F* (13, 126)=27.77, p < 0.01, $\dot{\eta}_p^2 = 0.62$). A statistically significant (F (13, 126)=14.41, p < 0.01, $\dot{\eta}_p^2 = 0.60$) interaction between demand and concept was also observed. Emissions were statistically significantly higher (p < 0.05) in the high demand RTPD condition than the low demand condition. Further analysis revealed bearing had statistically significantly (p < 0.05) more emissions than all other information except course and speed. Course and speed had statistically significantly (p < 0.05) more emissions than all other information except contact, solution, and range. Bearing, contact, course, solution, speed, and range had statistically significantly more emissions in the high demand scenarios compared to the low demand (see Table 7).

The total emissions of each node were statistically significantly affected by configuration type (F(1, 252) = 35.53, p < 0.05, $\dot{\eta}_p^2 = 0.12$). The total number of emissions were statistically significantly (p < 0.05) lower in the circle configuration.

3.2.2.2 Receptions In the circle configuration the total receptions of each node were statistically significantly affected by scenario demand ($F(1, 126) = 171.73, p < 0.01, \dot{\eta}_p^2 = 0.58$) and concept type ($F(13, 126) = 27.77, p < 0.01, \dot{\eta}_p^2 = 0.74$). A statistically significant ($F(13, 126) = 14.41, p < 0.01, \dot{\eta}_p^2 = 0.60$) interaction between demand and concept was also observed. Receptions were statistically significantly higher (p < 0.05) in the high demand RTPD condition than the low demand condition. Further analysis revealed bearing had statistically significantly (p < 0.05) more receptions than all other information except course and speed. Course and speed had statistically significantly

(p < 0.05) more receptions than all other information except contact, solution, and range. Bearing, contact, course, solution, speed, and range had statistically significantly more receptions in the high demand scenarios compared to the low demand. The total receptions of each node were statistically significantly affected by configuration type (*F* (1, 252)=34.57, p < 0.05, $\hat{\eta}_p^2 = 0.12$). The total number of receptions were statistically significantly (p < 0.05) lower in the circle configuration.

3.2.2.3 Sociometric status In the circle configuration the sociometric status of each node was statistically significantly affected by scenario demand (F (1, 126)=97.41, p < 0.01, $\hat{\eta}_p^2 = 0.44$) and concept type (F (13, 126)=28.96, p<0.01, $\dot{\eta}_{p}^{2} = 0.75$). A statistically significant (F (13, 126) = 10.85, p < 0.05, $\eta_p^2 = 0.53$) interaction between demand and concept was also observed. Sociometric status was statistically significantly higher (p < 0.05) in the high demand RTPD condition than the low demand condition. Further analysis revealed bearing had statistically significantly (p < 0.05)higher sociometric status than all other information except course and speed. Course and speed had statistically significantly (p < 0.05) higher sociometric status than all other information except contact, solution, and range. Bearing, course, solution, and range had statistically significantly higher sociometric status in the high demand scenarios compared to the low demand scenarios.

The sociometric status of each node was statistically significantly affected by configuration type (F(1, 252) = 36.77, p < 0.01, $\dot{\eta}_p^2 = 0.13$). A statistically significant interaction between configuration, information type and demand (F(1, 252) = 1.76, p < 0.01, $\dot{\eta}_p^2 = 0.08$) was also observed. Sociometric status was statistically significantly (p < 0.05) lower in the circle configuration. The sociometric status of bearing, course, and solution was statistically significantly (p < 0.05) lower in the circle configuration low demand scenarios compared to the baseline low demand scenarios. The sociometric status of sonar and speed was statistically significantly (p < 0.05) lower in the circle configuration high demand scenarios compared to the baseline high demand scenarios.

)					
	Emission				Reception			
	Baseline		Circle		Baseline		Circle	
	Low	High			Low	High		
Bearing	206.30 ± 158.06	270.10 ± 234.33	82.18±21.46	229.6 ± 75.53	206.30 ± 158.06	255.30 ± 193.91	82.18±21.46	229.6 ± 75.53
Contact	94.90 ± 37.02	146.10 ± 84.67	68.1 ± 29.77	124.44 ± 51.78	94.90 ± 37.02	152.60 ± 102.86	68.1 ± 29.77	124.44 ± 51.78
Course	178.36 ± 104.45	201.25 ± 165.25	75.5 ± 27.97	155.3 ± 54.31	178.36 ± 104.45	207.73 ± 179.15	75.5 ± 27.97	155.3 ± 54.31
Look	79.58 ± 36.75	67.22 ± 34.71	23.27 ± 19.9	39.6 ± 17.26	79.58 ± 36.75	66.17 ± 36.49	23.27 ± 19.9	39.6 ± 17.26
Merge	89.76 ± 67.57	71.40 ± 73.51	20.44 ± 25.7	15.5 ± 10.11	89.76 ± 67.57	77.90 ± 92.31	20.44 ± 25.7	15.5 ± 10.11
Periscope	115.59 ± 105.10	122.94 ± 158.76	49.8 ± 13.51	60.6 ± 21.61	115.59 ± 105.10	112.16 ± 125.55	49.8 ± 13.51	60.6 ± 21.61
Priority	38.60 ± 22.83	74.80 ± 60.15	13.92 ± 10.94	23.13 ± 14.71	38.60 ± 22.83	73.60 ± 56.87	13.92 ± 10.94	23.13 ± 14.71
Solution	183.60 ± 178.31	164.30 ± 144.30	59.4 ± 31.73	134.1 ± 38.53	183.60 ± 178.31	164.50 ± 144.83	59.4 ± 31.73	134.1 ± 38.53
Sonar	68.90 ± 96.73	130.79 ± 237.70	17.79 ± 14.7	31.55 ± 44.76	68.90 ± 96.73	161.70 ± 331.01	17.79 ± 14.7	31.55 ± 44.76
Speed	188.40 ± 103.97	251.15 ± 207.59	85.3 ± 31.84	153.9 ± 63.73	188.40 ± 103.97	249.66 ± 201.04	85.3 ± 31.84	153.9 ± 63.73
Sweep	32.90 ± 15.82	31.70 ± 21.28	11.6 ± 5.17	15.1 ± 11.26	32.90 ± 15.82	28.77 ± 15.11	11.6 ± 5.17	15.1 ± 11.26
Depth	133.03 ± 108.82	112.52 ± 81.57	45.6 ± 16.01	58.04 ± 21.61	133.03 ± 108.82	109.37 ± 73.45	45.6 ± 16.01	58.04 ± 21.61
Range	133.80 ± 156.47	170.01 ± 121.53	50.01 ± 16.37	116.51 ± 60.79	133.80 ± 156.47	173.27 ± 128.13	50.01 ± 16.37	116.51 ± 60.79
Visual	34.94 ± 19.80	22.42 ± 29.50	13.77 ± 12.95	19.47 ± 23.16	34.94 ± 19.80	24.45 ± 34.35	13.77 ± 12.95	19.47 ± 23.16
Effect of Demand	5.35*		171.73^{***}		4.91*		171.73^{***}	
Effect of Concept	3.52***		27.77***		3.22***		27.77***	
Demand*Concept	1.22		14.41^{***}		1.20		14.41^{***}	
Effect of Configuration	35.51***		171.73^{***}		34.57***			
Effect of	0.53				0.52			
Configuration*information								
Effect of Configuration*info*Deman	1.41 d				1.58			
,	Sociometric				Centrality			
	Baseline		Circle		Baseline		Circle	
	Low	High			Low	High		
Bearing	9.72 ± 7.62	11.63 ± 8.36	4.22 ± 1.25	9.97 ± 3.46	30.33 ± 3.55	30.08 ± 4.85	22.95 ± 8.18	31.46 ± 3.64
Contact	4.59 ± 1.58	6.62 ± 3.39	3.42 ± 1.28	5.36 ± 2.36	29.9 ± 5.02	31.65 ± 4.77	27.62 ± 4.16	33.34 ± 3.72
Course	8.18 ± 4.73	8.48 ± 6.32	3.87 ± 1.32	6.72 ± 2.35	28.54 ± 4.67	28.42 ± 3.30	23.72 ± 4.04	29.38 ± 2.73
Look	3.53 ± 1.74	3.14 ± 1.7	1.13 ± 0.86	1.71 ± 0.75	26.9 ± 3.2	25.94 ± 3.83	26.08 ± 12.58	28.52 ± 3.28
Merge	3.87 ± 2.97	3.39 ± 3.24	0.96 ± 1.08	0.67 ± 0.43	25.26 ± 5.41	23.82 ± 4.45	25.80 ± 18.41	21.57 ± 3.06
Periscope	5.25 ± 5.05	5.07 ± 5.21	2.6 ± 0.85	2.6 ± 0.88	27.8 ± 4.23	24.97 ± 5.23	25.86 ± 3.48	30.05 ± 3.51
Priority	1.72 ± 0.87	3.39 ± 2.4	0.73 ± 0.57	0.97 ± 0.54	24.36 ± 4.63	25.80 ± 3.95	22.7 ± 11.06	26.4 ± 3.32

	Baseline		Circle		Baseline		Circle	
	Low	High			Low	High		
Solution	8.16 ± 8.66	6.97 ± 5.31	2.98 ± 1.45	5.81 ± 1.74	28.57 ± 4.74	28.07 ± 5.97	24.27 ± 4.93	30.78 ± 2.27
Sonar	3.22 ± 4.74	6.07 ± 10.81	0.89 ± 0.67	1.29 ± 1.74	24.86 ± 4.16	26.46 ± 5.30	26.68 ± 14.65	25.85 ± 5.15
Speed	8.48 ± 4.82	11.11 ± 7.85	4.45 ± 1.8	6.66 ± 2.7	28.45 ± 5.31	28.09 ± 5.45	24.01 ± 3.05	27.78 ± 3.2
Sweep	1.48 ± 0.72	1.33 ± 0.69	0.59 ± 0.23	0.64 ± 0.48	23.24 ± 3.77	22.04 ± 3.56	19.06 ± 2.47	23.89 ± 2.71
Depth	5.96 ± 4.93	4.88 ± 2.96	2.4 ± 1.04	2.48 ± 0.82	28.11 ± 4.37	26.10 ± 4.47	25.45 ± 2.5	29.57 ± 3.08
Range	6.34 ± 7.68	7.54 ± 5.06	2.63 ± 0.99	5.03 ± 2.65	26.21 ± 3.44	25.87 ± 3.99	22.37 ± 5.14	27.48 ± 1.98
Visual	1.53 ± 0.85	0.94 ± 1.2	0.71 ± 0.65	0.83 ± 1	22.8 ± 3.79	20.73 ± 3.27	24.72 ± 12.48	24.77 ± 2.28
Effect of Demand	3.31^{t}		97.41***		1.30		20.44^{***}	
Effect of Concept	3.85***		28.96^{***}		5.36***		1.87*	
Demand*Concept	1.25		10.85^{***}		0.67		1.26	
Effect of Configuration	36.77***				0.94			
Effect of	0.53				1.13			
Configuration*information								
Effect of	1.76^{*}				1.26			
Configuration*info*Deman	pt							

Centrality

Sociometric

Table 7 (continued)

3.2.2.4 Centrality In the circle configuration the centrality status of each node was statistically significantly affected by scenario demand ($F(1, 126) = 20.44, p < 0.01, \dot{\eta}_p^2 = 0.14$) and concept type ($F(13, 126) = 1.87, p < 0.05, \dot{\eta}_p^2 = 0.16$). In the high demand scenarios centrality was statistically significantly (p < 0.05) higher compared to the low demand. Further analysis revealed contact had statistical significantly (p < 0.05) higher sociometric status than sweep.

3.3 Task network analysis

The type of tasks completed by the command team was the same during the baseline and the circle configuration (for both high and low demand scenarios) as the fundamental task completed by operators did not change. The command team were required to complete a variety of subtasks (e.g. detect and designate sonar contacts), to build a sonar picture that promotes awareness of surrounding contacts, before a submarine is permitted to RTPD (see Fig. 4).

The task with the highest number of emissions was 'building the sonar picture' which required the completion of numerous subtasks (i.e. data analysis and assimilation) to inform the generation of a tactical picture when operating at depth (see Table 8). The verification of tasks networks by SMEs provided the basis for the completion of task frequency analysis.

3.3.1 Task frequency analysis

In the circle configuration the frequency of task completion was statistically significantly affected by scenario demand $(F (1, 189) = 290.72, p < 0.01, \dot{\eta}_p^2 = 0.61)$ and task type (F $(20, 189) = 43.34, p < 0.01, \dot{\eta}_p^2 = 0.82)$. A statistically significant interaction (F (20, 189) = 31.59, p < 0.01, $\hat{\eta}_p^2 = 0.77$) between scenario demand and task type was also observed. Post-hoc analysis revealed the frequency of task completion was statistically significantly higher (p < 0.05) in the high demand condition than the low demand condition. The tasks detecting, designating, classifying, checking cuts, and generating solutions from sonar were completed statistically significantly (p < 0.05) more frequently in the high demand condition. Further analysis revealed the tasks of detecting, designating, classifying, generating speed estimates, and generating (and refining) solution estimates from sonar were completed statistically significantly (p < 0.05) more frequently than all other tasks (see Table 9). Further analysis revealed the tasks of detecting, designating, generating speed estimates, and generating solutions from sonar were completed statistically significantly (p < 0.05) more frequently than classifying sonar contacts, refining solutions, and making changes to own submarines parameters in the high demand condition but not in the low demand condition (see Table 9).

The frequency of task completion was statistically significantly affected by configuration (F(1, 378) = 7.07, p < 0.01, $\dot{\eta}_p^2 = 0.43$), the interaction of configuration and task type (F $(20, 378) = 4.71, p < 0.01, \dot{\eta}_p^2 = 0.20)$ and the interaction of configuration, task type and demand (F (20, 378) = 6.52,p < 0.01, $\eta_p^2 = 0.26$). Further analysis revealed statistically significantly (p < 0.05) more tasks were completed in the circle configuration than the baseline configuration. The tasks detecting and designating on sonar were completed statistically significantly (p < 0.05) more frequently in the circle configuration compared to baseline. The tasks of detecting sonar contacts, checking cuts, designating sonar contacts and completing sonar merges were completed statistically significantly (p < 0.05) more frequently in the high demand circle configuration than in the baseline high demand scenarios. The task of classifying and generating course estimates for sonar contacts was completed statistically significantly (p < 0.05) more frequently in the baseline high demand scenarios compared to the circle configuration baseline scenarios.

3.4 Summary of results

As the previous sections have shown, for most of the team process measures (i.e., social network analysis, information network analysis and task network analysis) performance was superior in the inward-looking, circle, configuration when compared to the traditional two-room layout of the control room. In addition, when speaking with the expert submariners immediately after testing the circle configuration, the following comments were elicited:

- "The layout is better than I was expecting and is a step towards improving the flow of information and communication between team members"
- "Realistic circular style control room with massive potential for future development. Advancing how submariners will carry out their jobs in the future."
- "The circular layout allows for a lot of non-verbal information to be passed."
- "The set up and feel of the room is a vast improvement form the baseline setup [Traditional two-room layout]. This current configuration feels like a good submarine control room layout, thus ensuring all tasks were competed successfully."
- "The new trainer set up is an improvement and I feel this would be a good setup for future control rooms. Having contact with everyone in the control room helps to build a picture. I think this is a good way to all face inwards and for the OOW to see what is going on."

Fig. 4 Task network diagrams for RTPD low and high demand scenarios (baseline and circle configuration)



• "New layout has improved communication between OOW/OPS and all outstations. Does provide the ability to communicate non-verbally which in certain situations (e.g., RTPD) is extremely useful."

In summary, the expert submariners were very favourable in their comments on the new inward-facing, circle, configuration of the control room an opined that it was superior to the traditional, two-room, layout.

4 Discussion

In the circle configuration, operators coped with an increase in demand by increasing the total number of communications; similar to what had been observed previously in the baseline configuration and the co-location study (Stanton et al. 2017; Stanton and Roberts 2020a, b). This was to be expected due to the greater number of contacts the command team were required to manage in the high demand scenario.

	Emission	Reception	Sociometric	Centrality	Closeness	Farness	Betweeness	Eccentricity
OOW brief	1	4	0.19	11.18	0.16	159	40.00	12
Detect contacts sonar	3	2	0.19	12.59	0.19	134	69.23	11
Close sonar contact	3	2	0.19	14.04	0.22	120	73.71	10
Designate sonar contact	2	2	0.15	11.35	0.17	153	77.00	12
Classify Sonar Contacts	3	1	0.15	11.72	0.19	137	41.04	11
Speed estimates	1	3	0.15	11.07	0.17	157	3.50	11
Sonar Courses	1	1	0.08	10.29	0.17	154	0.50	11
Identify sonar merges	2	2	0.15	12.24	0.21	124	68.35	10
Check cuts are received	2	1	0.12	11.35	0.18	143	33.96	11
Build Sonar Picture	4	1	0.19	12.96	0.25	104	36.45	9
Generate Solutions	1	3	0.15	12.66	0.20	133	63.65	10
Steer safe course	2	2	0.15	13.04	0.21	126	49.00	9
Refine solutions	3	3	0.23	14.14	0.24	109	121.05	9
Clear Stern arcs	2	3	0.19	13.52	0.21	125	174.56	8
Final Reports	3	1	0.15	14.23	0.24	108	174.00	7
Silent Routines	1	1	0.08	22.13	0.68	38	75.00	6
Normal Routines	1	1	0.08	22.13	0.68	38	75.00	6
RTPD	1	2	0.12	20.67	0.93	28	153.00	5
Raise Periscope	2	2	0.15	18.11	1.37	19	158.00	4
1st Sweep	1	1	0.08	16.85	4.33	6	54.00	3
Detect Close Visual	1	1	0.08	14.61	8.67	3	34.00	2
First Reports	1	1	0.08	12.74	26.00	1	12.00	1
ESM check	1	1	0.08	15.01	1.00	26	69.00	6
Confirm Submarine safe	2	1	0.12	13.78	1.24	21	56.00	5
Raise WT mast	1	1	0.08	13.61	26.00	1	12.00	1
Lower Periscope	1	1	0.08	12.17	1.08	24	9.00	5
Complete mission	0	2	0.08	11.59	0.00	0	0.00	0

Table 8 Task network metrics for individual nodes RTPD scenarios high and low demand scenarios (baseline and circle configuration)

The total number of interactions, number of edges, and density of the social networks was significantly lower in the circle configuration, with total interactions in the circle high demand comparable to those of the baseline low demand (Stanton et al. 2017). This indicates that the command team were communicating less frequently, between fewer operators, meaning that the social network was less cluttered. However, in the circle configuration cohesion was significantly greater, indicating that, despite fewer interactions, the network was actually more connected. It appears that the co-location element of the circular configuration has reduced the bottleneck between the OPSO and SOC, with emissions from these operators seeing the greatest reduction (Stanton et al. 2017; Stanton and Roberts 2020a, b). This frees these operators to focus on overseeing the work of the TMAs and SOPs rather than passing information between the TMAs and SOPs (Stanton et al. 2017; Stanton and Roberts 2020a, b). The inwards facing design with duplicate work screens allowed all operators to see what each other was working on, and potentially receive information without verbally requesting it (Clark and Brennan 1991; McNeill 1992). This design permitted face-to-face communication between operators that is characteristic of traditional co-located teams (Hamburger et al. 2011). This may have facilitated the reduction in communications due to the potential to use non-verbal cues (Boyle et al. 1994; Hendy et al. 2000; Cassell et al. 2001).

The emissions and receptions of all operators were reduced in the circle configuration, with the exception of TMA1 and TMA2 in the high demand scenario. It may be that the circle configuration facilitated a greater number of communications by these operators as they were able to request information when they needed it, from the operator they needed it from. In the circle configuration, the sociometric status of the more senior operators (OOW, OPSO, SOC) was significantly lower than in the baseline study (Stanton et al. 2017). This may reflect the fact that the bottleneck of information between these operators was reduced meaning that information was able to flow around them, rather than through them. Despite this, the centrality of the OOW, OPSO, and SOC was still greater than all other operators, highlighting their importance to command room operations (Stanton et al. 2017). A key issue with the

Table 9 Frequency of task completion RTPD scenarios

baseline and circle configuration

Demand	RTPD				
	Baseline		Circle		
	Low	High	Low	High	
Detect sonar contacts	4±1.89	8.7±4.22	2.9 ± 0.74	17.6 ± 5.15	
Designate sonar contacts	3.3 ± 1.64	7.7 ± 4.85	3.4 ± 1.78	14.2 ± 2.86	
Classify sonar contacts	3.8 ± 1.87	10.5 ± 4.3	1.9 ± 1.52	6.8 ± 3.79	
Sonar speed estimates	5.4 ± 2.27	10.9 ± 5.67	5.4 ± 2.5	9.2 ± 4.98	
Sonar course estimates	1.2 ± 1.23	4.9 ± 2.13	2.4 ± 1.96	2.6 ± 2.55	
Check cuts	2.4 ± 1.84	3.9 ± 1.52	2.3 ± 1.16	8.6 ± 3.57	
Sonar merges	3.4 ± 1.35	2.8 ± 1.81	2.7 ± 1.06	6.7 ± 1.57	
Sonar solution	4.6 ± 1.96	10.7 ± 3.53	4 ± 0.47	12.6 ± 3.47	
Refine solutions	4.2 ± 3.58	5.1 ± 3.63	5.3 ± 1.95	7.7 ± 3.47	
Change submarine parameters	4.4 ± 2.46	4.3 ± 2.06	3.7 ± 1.06	3.8 ± 1.14	
Raise periscope	1 ± 0	0.8 ± 0.42	1.1 ± 0.32	1.1 ± 0.32	
Complete sweep	1.8 ± 0.63	0.8 ± 0.42	1.2 ± 1.03	1.3 ± 0.67	
Detect visual contacts	1.7 ± 0.95	1.4 ± 1.07	2.4 ± 1.17	3.2 ± 1.48	
Designate visual contacts	1.3 ± 1.06	1.1 ± 1.1	1.8 ± 1.48	2.7 ± 2	
Classify visual contacts	0.7 ± 0.82	1.1 ± 2.02	0.1 ± 0.32	0 ± 0	
Range visual contacts	0.8 ± 1.03	1.6 ± 2.5	0.2 ± 0.42	0.4 ± 0.7	
Course estimates of visual	0.4 ± 0.97	1 ± 2.83	0.2 ± 0.42	0.5 ± 1.27	
Visual solutions	0.1 ± 0.32	0.1 ± 0.32	0 ± 0	0 ± 0	
Merge visual and sonar	0.7 ± 0.82	0.3 ± 0.95	0.1 ± 0.32	0 ± 0	
Clear stern arcs	1 ± 0	1 ± 0.47	1 ± 0	1.1 ± 0.32	
Final reports	1 ± 0	0.9 ± 0.32	1 ± 0	1 ± 0	
Effect of demand	57.41***		290.72***		
Effect of task type	25.20***		43.34***		
Demand*task	7.09***		31.59***		
Effect of Configuration	7.07***				
Effect of Configuration*task	4.71***				
Effect of Configuration*Task*Demand	6.52***				

co-location studies previously conducted was that the OOW was on the periphery of the command team (Stanton and Roberts 2020a, b; Roberts et al. 2019). In the current work, the OOW was in a central position as so was able to observe all operators and tasks being conducted. As the OOW was central to the information flow, both verbally and visually, they were able to troubleshoot more effectively.

In the circle configuration, the top 14 concepts remained the same as in the baseline study, indicating that the circle configuration had not affected the type of information most important to the RTPD operation (Stanton et al. 2017). When examining the information networks, there were significantly more nodes, edges, and total emissions in the high demand scenario, suggesting that as well as communicating more frequently in response to demand, operators also communicated a wider range of information. This effect of demand was not observed in the baseline study (Stanton et al. 2017) but was observed when operators dependent on each other for task-relevant information were co-located (Stanton and Roberts 2020a). The density of the information networks was significantly lower in the circle configuration compared to the baseline study. As task-dependent operators were co-located in the circle configuration they were able to request information when it was required. Therefore, communications contained only the necessary information and were not passed by multiple operators (Stanton and Roberts 2020a). Furthermore, as emissions and receptions of concepts were statistically significantly lower in the circle configuration, it seems that the increase in total emissions came from additional information that was not able to be provided during the baseline study, rather than repetition of key concepts.

The type of tasks completed by the command team was the same during the circular configuration and the baseline study as the task completed by operators did not change. When examining the effect of scenario demand on task completion in the circle configuration, results were comparable to the baseline study, with more tasks being completed in the high demand scenario due to the greater number of contacts the command team were required to manage (Stanton et al. 2017). Overall, a significantly greater number of tasks were completed in the circle configuration compared to the baseline study, in particular, the tasks of detection and designation of contacts. These tasks form the foundation of all other sonar tasks and are key for maintaining awareness of vessels surrounding own-ship (Stanton 2014). It appears that the inwards facing circular configuration increased overall productivity and was well-liked by the expert submariners.

There are two potential limitations associated with this research, however, which are the use of novice submariner participants and the lack of objective measures of performance. As noted earlier, whilst it might be ideal to have 10 teams of serving submariners this is not practically achievable given current operational demands on the Royal Navy. Whilst there is a case to be made for single team studies (Stanton and Roberts 2020b) for the purposes of statistical analysis greater numbers are required. Previous research has shown that the expert teams are faster and complete more task than their novice counterparts but they do not undertake fundamental different activities (Stanton and Roberts, 2017, 2020a). Whist the study reported in this paper focused on the team processes (i.e., communications between team members, information exchanged and tasks performed) it did not report on team performance in terms of tactical picture accuracy. Future research needs to develop robust methods for analysing the accuracy of the tactical picture and reporting on the effects of different control room configurations. It is anticipated the inward-facing, circular, configuration tactical picture would be as least as good as the traditional, two-room, layout. Given that more information was conveyed and more tasks were completed in the inward-facing, circular, configuration it is hoped that the tactical picture accuracy would be improved.

5 Summary and conclusions

The current work compared an inward-facing circular configuration to a contemporary outwards facing submarine control room during the completion of high and low demand RTPD scenarios. The novel circular configuration led to a more cohesive command team who communicated in a more concise manner, exchanging a greater volume of information and completing a greater number of tasks. As observed previously, the co-location of the operators dependent on each other for task-relevant information relieved the bottleneck of information between the OPSO and the SOC (Stanton and Roberts 2020a, b; Roberts et al. 2019). The inwards facing, circular, design permitted face-to-face communication between operators that is characteristic of traditional co-located teams (Hamburger et al. 2011). This may have facilitated the reduction in communications due to the potential to use non-verbal cues (Boyle et al. 1994; Hendy et al. 2000; Cassell et al. 2001).

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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References

- Ahlstrom U, Friedman-Berg FJ (2006) Using eye movement activity as a correlate of cognitive workload. Int J Ind Ergon 36:623–636. https://doi.org/10.1016/j.ergon.2006.04.002
- Argyle M, Dean J (1965) Eye-contact, distance and affiliation. Sociometry 28:289–304
- Boyle EA, Anderson AH, Newlands A (1994) The effects of visibility on dialogue and performance in a cooperative problem solving task. Lang Speech 37:1–20
- Cassell J, Bickmore T, Campbell L et al (2001) More than just a pretty face: conversational protocols and the affordances of embodiment. Knowl Based Syst 14:55–64. https://doi.org/10.1016/S0950 -7051(00)00102-7
- Clark HH, Brennan SE (1991) Grounding in communication. Perspect Soc Shar Cogn 13:127–149
- Cramton CD (2001) The mutual knowledge problem and its consequences for dispersed collaboration. Org Sci 12:346–371. https:// doi.org/10.1287/orsc.12.3.346.10098

- Crockford I, Breton M, Mccormick F, Johnson P (2011) Delivering London 2012: the Olympic stadium. Proc Inst Civ Eng Civ Eng 164:37–43. https://doi.org/10.1680/cien.2011.164.6.37
- Dinges DF, Rider RL, Dorrian J et al (2005) Optical computer recognition of facial expressions associated with stress induced by performance demands. Aviat Sp Environ Med 76
- Dominguez C, Long WG, Miller TE, Wiggins SL (2006) Design directions for support of submarine commanding officer decision making. In: Proceedings of 2006 Undersea HSI symposium: research, acquisition and the warrior, pp 6–8
- Falout J (2014) Circular seating arrangements: approaching the social crux in language classrooms. Stud Second Lang Learn Teach 2:275–300. https://doi.org/10.14746/ssllt.2014.4.2.6
- Fay D, Stanton NA, Roberts APJ (2019) All at sea with user interfaces: from evolutionary to ecological design for submarine combat systems. Theor Issues Ergon Sci 20:632–658. https://doi. org/10.1080/1463922X.2019.1582115
- Gardin H, Kaplan KJ, Firestone IJ, Cowan GA (1973) Proxemic effects on cooperation, attitude, and approach-avoidance in a Prisoner's Dilemma game. J Pers Soc Psychol 27:13
- Halverson T, Estepp J, Christensen J, Monnin J (2012) Classifying workload with eye movements in a complex task. Proc Hum Factors Ergon Soc. https://doi.org/10.1177/1071181312561012
- Hamburger P, Miskimens D, Truver S (2011) It is not just hardware and software, anymore! Human systems integration in US submarines. Nav Eng J 123:41–50. https://doi.org/10.111 1/j.1559-3584.2009.00198.x
- Heath C, Luff P (1991) Collaborative activity and technological design: Task coordination in London Underground control rooms. In: Proceedings of the Second European conference on computer-supported cooperative work ECSCW'91. Springer, pp 65–80
- Hendy KC, Edwards JL, Beevis D, Hamburger T (2000) Analysing advanced concepts for operations room layouts. Proc XIVth Trienn Congr Int Ergon Assoc 44th Annu Meet Hum Factors Ergon Assoc'Ergonomics New Millenn 514–517. https://doi. org/10.1177/154193120004403617
- Hewish M (2002) Submarines to cast off their shackles, take on new roles. Int Def Rev
- Hinds PJ, Bailey DE (2003) Out of sight, out of sync: understanding conflict in distributed teams. Org Sci. https://doi.org/10.1287/ orsc.14.6.615.24872
- Houghton RJ, Baber C, McMaster R et al (2006) Command and control in emergency services operations: a social network analysis. Ergonomics 49:1204–1225
- Khan A, Matejka J, Fitzmaurice G, Kurtenbach G (2005) Spotlight: directing users' attention on large displays. In: Proceedings of the SIGCHI conference on Human facotrs in computing systems. ACM, pp 791–798
- Kirschenbaum SS, Trafton JG, Schunn CD, Trickett SB (2014) Visualizing uncertainty: the impact on performance. Hum Factors 56:509–520
- MacMillan J, Paley MJ, Entin EB, Entin EE (1999) Questionnaires for distributed assessment of team mutual awareness. In: Stanton NA, Hedge A, Brookhuis KA et al (eds) Handbook of human factors and ergonomics methods. CRC Press, Boca Raton, FL, pp 484–494
- Masakowski YR (2000) Optimized Manning for the 21st Century. In: 36th IAMPS, pp 173–176
- Masakowski YR, Hardinge N (2000) Comparing the cognitive decison-making strategies of US and UK Naval Sonar operators. 36th IAMPS. Split, Croatia, pp 167–172
- McNeill D (1992) Guide to gesture classification, transcription, and distribution. Hand and mind what gestures reveal about thought. The University of Chicago Press, Chicago, pp 75–104
- Perkins D (2003) King Arthur's round table: how collaborative conversations create smart organizations. Wiley, Amsterdam

- Roberts APJ, Stanton NA, Fay D (2015) The command team experimental test-bed stage 1: design and build of a submarine command room simulator. Proc Manuf 3:2800–2807
- Roberts APJ, Stanton NA, Fay D (2017a) Land ahoy! Understanding submarine command and control during the completion of inshore operations. Hum Factors 59:1263–1288
- Roberts APJ, Stanton NA, Fay D (2017b) The command team experimental test-bed phase two: assessing cognitive load and situation awareness in a submarine control room. In: Stanton NA, Landry S, Di Bucchianico G, Vallicelli A (eds) Advances in human aspects of transportation. Advances in intelligent systems and computing. Springer, Cham, pp 427–437
- Roberts APJ, Stanton NA, Fay D (2018) Go deeper, go deeper: understanding submarine command and control during the completion of dived tracking operations. Appl Ergon 69:162–175
- Roberts APJ, Stanton NA, Fay D, Pope KA (2019) The effects of team co-location and reduced crewing on team communication characteristics. Appl Ergon 81:102875. https://doi.org/10.1016/j.aperg o.2019.102875
- Salas E, Grossman R, Hughes AM, Coultas CW (2015) Measuring team cohesion: observations from the science. Hum Fact 57(3):365–374
- Salmon PM, Lenné MG, Walker GH et al (2014) Using the Event Analysis of Systemic Teamwork (EAST) to explore conflicts between different road user groups when making right hand turns at urban intersections. Ergonomics 57:1628–1642. https://doi.org/10.1080/00140 139.2014.945491
- Scott R (2017) Leaving the periscope behind: optronic masts transform the above-water picture. Jane's Navy Int 122:22
- Stanton NA (2014) Representing distributed cognition in complex systems: how a submarine returns to periscope depth. Ergonomics 57:403–418
- Stanton NA, Bessell K (2014) How a submarine returns to periscope depth: analysing complex socio-technical systems using Cognitive Work Analysis. Appl Ergon 45:110–125
- Stanton NA, Harvey C (2016) Beyond human error taxonomies in assessment of risk in sociotechnical systems: a new paradigm with the EAST "broken-links" approach. Ergonomics 60:221–233. https:// doi.org/10.1080/00140139.2016.1232841
- Stanton NA, Roberts APJ (2017) Examining social, information, and task networks in submarine command and control. IEEE Trans Hum Mach Syst 48:252–265. https://doi.org/10.1109/THMS.2017.27206 59
- Stanton NA, Roberts APJ (2020a) Block off: an examination of new control room configurations and reduced crew sizes examining engineered production blocking. Cogn Technol Work 22:29–55. https:// doi.org/10.1007/s10111-019-00542-x
- Stanton NA, Roberts APJ (2020b) Better together? Investigating new control room configurations and reduced crew size in submarine command and control. Ergonomics 63:307–323. https://doi. org/10.1080/00140139.2019.1654137
- Stanton NA, Baber C, Harris D (2008) Modelling command and control: event analysis of systemic teamwork. CRC Press, Boca Raton, FL
- Stanton NA, Roberts APJ, Fay D (2017) Up periscope: understanding submarine command and control teamwork during a simulated return to periscope depth. Cogn Technol Work 19:399–417. https:// doi.org/10.1007/s10111-017-0413-7
- Stanton NA, Salmon PM, Walker GH (2019) Systems thinking in practice: applications of the event analysis of systemic teamwork method. CRC Press, Boca Raton
- Stewart R, Stanton NA, Harris D et al (2008) Distributed situation awareness in an Airborne Warning and Control System: application of novel ergonomics methodology. Cogn Technol Work 10:221–229. https://doi.org/10.1007/s10111-007-0094-8
- Walker GH, Stanton NA, Baber C et al (2010) From ethnography to the EAST method: a tractable approach for representing distributed

cognition in Air Traffic Control. Ergonomics 53:184–197. https:// doi.org/10.1080/00140130903171672

- Wichman H (1970) Effects of isolation and communication on cooperation in a two-person game. J Pers Soc Psychol 16:114–120. https:// doi.org/10.1037/h0029845
- Zarnich RE (1999) A fresh look at broadband passive sonar processing. In: adaptive sensor array processing workshop, Office of Naval Research, pp. 99–104

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