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ORIGINAL ARTICLE

Ship Leadership, Situation Awareness, and Crew Safety Behaviour—Preregistered Replications in Two Survey Datasets

Bjørn Sætrevik and Sigurd Hystad

Situation awareness is often assumed to be crucial for working safely. Self-reported context-general measures can be an efficient way to measure situation awareness in large datasets and test how it relates to other individual, organizational, and environmental variables. In a previous structural equation model (Sætrevik & Hystad, 2017) authentic leadership accounted for situation awareness and self-report of committing unsafe actions, while situation awareness accounted for subjective risk assessment and commitment of unsafe actions. The current study performed preregistered replications of the same associations in two novel but similar datasets. Both datasets replicated that higher situation awareness was associated with fewer unsafe actions and with lower subjective risk assessment. One of the new datasets measured leadership, and more authentic leadership was found to be associated with higher situation awareness and fewer unsafe actions. The preregistered structural equation models explained large amounts of the variance in situation awareness and unsafe actions and medium to large amounts of the variance in subjective risk assessment. We also tested adjusted models that incorporated more of the measured items and improved the validity of the measures. The study supports the claim that a crewmember's cognitive states (such as perception, understanding, and prediction of safety signals) are associated with safety outcomes and that leadership qualities may facilitate this relationship. This preregistered replication in two novel datasets increases the reliability of the previously identified relationships.

Keywords: Authentic leadership; situation awareness; unsafe actions; safety management; offshore supply vessel

1. Introduction

Decisions about safety-critical behaviour (Mearns & Flin, 1995) are made based on the perception and understanding of the immediate environment. The immediate leadership may influence this through having transformative effects on the followers' motivation for trying to understand their environment and by providing a framework for how safety should be assessed (Kapp, 2012; Zohar, 2002). In a survey dataset collected in 2013 (Sætrevik & Hystad, 2017), crewmembers that thought their captain provided authentic leadership reported to have more accurate situation awareness. Authentic leadership and situation awareness were also associated with seeing their work as more dangerous and that they committed more unsafe actions in their daily work. In the current study, we seek to replicate the same associations in two additional datasets collected in the same setting in 2015 and 2017. A preregistered replication of a previous model could contribute to discerning arbitrary observations from establishing a predictable pattern that can be expected to be observed every time the variables are measured in similar settings.

University of Bergen, NO

Corresponding author: Bjørn Sætrevik (bjorn.satrevik@uib.no)

1.1. Situation awareness

Situation awareness has been suggested to be a crucial sharp-end indicator for safety across a number of safety settings (Stanton, Chambers, & Piggott, 2001). Situation awareness is often understood as the cognitive process and the resulting cognitive states involved when an operator engages with their environment and decides on a course of action. Situation awareness thus involves making a mental model of the safety-critical aspects of the work, which then forms the basis of assessment and decision-making (Endsley, 2004, 2015). Although both the definition and theoretical framework of situation awareness is subject to discussion and alternative concepts have been suggested (Dekker, Hummerdal, & Smith, 2010; Sarter & Woods, 1991), it remains an influential concept among safety researchers and practitioners. The dominant theoretical model is typically considered to be Endsley's (1995) three-levelled model. In this model, level 1 concerns being able to perceive the relevant features in the environment. In a maritime setting, an example may be to notice a change in the ship's course. Level 2 concerns using the perceived elements to build an understanding of the crucial elements of the environment. A maritime example would be to realize that the current course does not match the planned voyage schedule. Level 3 concerns anticipating how the environment will develop in the near future. An example of this would be to recognize that, unless adjusted, the current course and speed will soon lead to a grounding.

Situation awareness is traditionally measured in relation to a given task environment (Patrick & Morgan, 2010). In such measures, the operator is positioned in a specific task or scenario to handle, and measures are made of the operator's actions (process measure), the accuracy of their beliefs (objective measure), or self-reported performance (subjective measure). We have previously argued (Sætrevik, 2013) that it will be valuable to have an instrument that can be applied across different work contexts to measure the operator's overview of safety-critical aspects (i.e., a context-general measure of situation awareness). Operators who state that they generally have accurate situation awareness would be expected to make safer decisions in their day-to-day work and thus be less subject to accidents. Such instruments will allow us measure aspects of situation awareness by sending out surveys to larger samples that can be used to compare the degree of situation awareness between different organizational units, to test associations between situation awareness and other survey measures, or to test associations between situation awareness and the organization's safety outcomes. Such an approach could allow organizations to direct their safety management work to develop situation awareness where it is needed.

1.2. Safety outcomes of situation awareness

The maritime industry, which is the context for the present study, has been claimed to be the world's most hazardous occupation (Håvold & Nesset, 2009). The accident rates vary substantially by type of maritime work, weather conditions, organizational conditions, and safety regulations. The company where the current datasets were collected hire about 70 offshore service vessels to attend about 55 offshore hydrocarbon installations (both numbers varying somewhat over time). In the data collection period, the total recordable injury frequency (TRIF) for the company's maritime operations varied between 3.3 and 6.3, which corresponds to 57 annual personnel injuries in the fleet (for company-wide sustainability reports, see Equinor, 2021). The type of accident with the most catastrophic potential is a collision between a vessel and a hydrocarbon producing installation. During the data collection period, the company, at its most, recorded 20 annual cases of vessels on a collision course.

The safe operation of complex socio-technical systems, such as offshore service vessels, relies on a number of interacting factors. In comparable systems, skill-based slips and memory lapses have been associated with creating risk (Hobbs & Williamson, 2002; Reason, 1990; Rothblum, 2000; Sheridan, 2008). Thus, the accuracy of a crewmember's situation awareness may influence whether they are aware of safety-critical information and how their actions influence safety in their daily work. This may impact both their motivation and their ability to work safely. Work in the hydrocarbon energy sector is closely regulated by safety procedures and explicit expectations for safety attitudes and behaviours (Norwegian Ministry of Labour and Social Affairs, 2018). We may thus expect (first hypothesis, H1) the crewmembers to have a clear idea of when their work follows the safety regulations and when they take risks that are not in compliance with the safety management system. In our previous study (Sætrevik & Hystad, 2017), one of the safety outcome measures was the crewmembers' self-report of engaging in various unsafe actions at work, in the sense of "cutting corners" in their adherence to the safety procedures. Previous studies have shown that committing unsafe actions is associated with increased risk of accidents and unwanted incidents (Hobbs & Williamson, 2002; Hofmann & Stetzer, 1996). This is not to say that identifying "human error" or "loss of situation awareness" is a satisfactory level of explanation for why accidents happen, as their underlying causes for this can be further explored and may present better targets for interventions.

Another safety outcome can be the crewmembers' impression of the level of safety on board. Such a measure will reflect not only the risks caused by their own work but also risks caused by the actions of their co-workers, risks caused by technical conditions, and risks that are seen as random or uncontrollable. The crew's subjective assessment of the level of risk could to some extent reflect the actual safety on board (Rhona Flin, Mearns, Gordon, & Fleming, 1996; Kirschenbaum, Oigenblick, & Goldberg, 2000; Sneddon, Mearns, & Flin, 2013), although the relationship may be complex and the causal direction unclear (Macrae, 2016). Our previous study (Sætrevik & Hystad, 2017) asked the respondents about the extent to which they perceive their work as dangerous, in terms of estimating the risk of being involved in an accident in the subsequent year. We may expect that (second hypothesis, H2) a crewmember that perceives and understands the safety-critical information will see their workplace as safer and that they are less at risk for an accident. While this does not directly address whether actual risk is associated with situation awareness, previous studies in comparable settings have indicated that inaccurate mental models may precede accidents (Endsley, 1995; Sneddon, Mearns, & Flin, 2006a).

1.3. Situation awareness and authentic leadership

Several studies have explored how accurate and suitable situation awareness may develop (Endsley, 2016; Jentsch, Salas, Sellin-Wolters, & Bowers, 1995). As mentioned above, situation awareness is often measured for a specific task rather than context generally, and experiments have manipulated aspects of the task or context (such as implementing a new control interface) rather than of individual, inter-individual, or organizational factors. This has led to identifying the impact on situation awareness of factors such as task complexity, workload, length of work shifts, time-of-day, stressors, and information presentation (Sandhåland, Oltedal, Hystad, & Eid, 2015; Sneddon et al., 2013). These findings have consequences for workplace design and organization, but it is uncertain how well the findings transfer to other work settings.

The concept of situation awareness is associated with cognitive psychology constructs, such as perception, schema, mental models, and mental simulation; sensemaking; and decision-making (Endsley, 2015; Sarter & Woods, 1991). Research has indicated that a generalized cognitive ability predicts performance in a number of job contexts (Ree, Earles, & Teachout, 1994; Schmidt & Hunter, 2004). Thus, a context-general situation awareness measurement can indicate individual variation in a crewmember's ability to perceive, understand, and make sense of their environments, which may have a predictive value for safety and performance in specific work situations.

Most safety-critical work is done in teams (Cannon-Bowers & Salas, 2016) within an organizational structure where the workers are in frequent interaction with formal or unformal leaders. For small teams in specialized and technical workplaces, such as on offshore supply vessels, much of the work is solitary, where the closest leader is one of a few points of contact during an average workday. The leader is likely to be a more experienced professional in the field who not only provides instructions and performance expectations but also guidance, advice, and expectations for how to work safely. The type and frequency of interaction with the closest leader may influence the operator's motivation to attend to safety issues and their capacity to develop situation awareness for safety in their daily work (Bolstad, Cuevas, & Costello, 2005; Sandhåland, Oltedal, Hystad, & Eid, 2017). The social environments and leaders may be particularly relevant for providing information, emphasis, and a framework for how to think about risks and safe behaviour. Social input from leaders may thus provide the workers with a source of safety information, guide them to what to attend to in their environment, provide models for how to work safely, demonstrate safety values, and motivate workers to maintain vigilance over time (Molnar, Schwarz, Hellgren, Hasson, & Tafvelin, 2019; Pilbeam, Doherty, Davidson, & Denyer, 2016). In small teams where some of the work is done individually (such as on an offshore supply vessel), the interaction with the team leader may be a crucial input to the worker's situation awareness. Whether the leader appears to take safety seriously, emphasizes the importance of following safety regulations and cares about the health of the workers is likely to be noticed by the workers and factored into the maintenance of safety in their day-to-day work (Molnar et al., 2019). Thus, the type of leadership provided may have an important role in enabling team members to develop situation awareness.

Several studies have examined the effect of leadership on safety in recent years (Conchie, Moon, & Duncan, 2013; Flin & Yule, 2004; Kim & Gausdal, 2017). The type of leadership has been found to be associated with safety climate, safety participation, and safety compliance (Clarke & Ward, 2006). In particular, leadership styles that emphasize the emotional relationship and growth between leader and follower may be effective in motivating employee participation in safety (Clarke, 2013; Smith, Eldridge, & DeJoy, 2016).

The concept of "authentic leadership" (Avolio & Gardner, 2005; Gardner, Cogliser, Davis, & Dickens, 2011) is used to describe leaders that are aware of and willing to share their strengths and weaknesses. They solicit and take into account opposing viewpoints and available information and are guided by internal moral standards rather than outside pressure. Authentic leadership is considered a root construct that can form the basis for other forms of positive leadership, such as transformational and ethical leadership (Avolio & Gardner, 2005). The advent of authentic leadership can be traced to the need for ethical leadership following the corporate scandals involving Enron and WorldCom in the early 2000s as well as the writings on transformational leadership, in which it was acknowledged that transformational leaders may not necessarily be authentic, as what they practice may be different from what they preach (Bass & Steidlmeier, 1999). It was therefore suggested that there are pseudo as well as authentic transformational leaders and that authentic leadership added ethics to transformational leadership (Lloyd-Walker & Walker, 2011). Both transformational and authentic leadership stress the idea of leading by example and are believed to stimulate personal identification among followers, but what separates authentic leaders is the centrality placed on transparency, positivity, and high ethical standards. Authentic leaders are aware of and willing to share their strengths and weaknesses, they solicit and consider opposing viewpoints and available information, and they are guided by internal moral standards rather than outside pressure (Walumbwa, Avolio, Gardner, Wernsing, & Peterson, 2008). It has been argued (Peus, Wesche, Streicher, Braun, & Frey, 2012) that self-knowledge and self-consistency are antecedents of authentic leadership and that it increases follower satisfaction, organizational commitment, and effectivity. Because authentic leaders are aware of how their behaviour and decisions will set standards and influence others, they are believed to act as positive role models for safety at work.

1.4. Previously identified associations to be replicated

Our previous study (Sætrevik & Hystad, 2017) analysed survey responses on several variables related to safety collected in 2013 from 705 crewmembers on 49 offshore supply vessels operating on the Norwegian Continental Shelf. We assumed that workers who prioritize safety goals will have a greater awareness of safety information and establish greater situation awareness during daily operations. Previous research has shown such associations both in the maritime and the oil and gas industries (Borgersen, Hystad, Larsson, & Eid, 2014; Hystad, Bartone, & Eid, 2014; Sandhåland et al., 2015; Hystad et al., 2013; Sandhåland et al., 2017). We thus assumed that crewmembers who report having authentic captains would have more accurate situation awareness. Our results showed that crewmembers that reported to have more accurate situation awareness performed fewer unsafe actions (H1 in Sætrevik & Hystad, 2017) and considered the risk for accidents to be lower (H2).

We further assumed that authentic leadership from captain's may influence and motivate the offshore service vessel crew to attend to safety in their work. Given the critical role of safety in the maritime sector (Sætrevik & Hystad, 2017), authentic leaders are expected to prioritize the health and safety of employees and to reflect these priorities in their behaviours and statements. Through role modeling and social identification processes, authentic leaders will influence others in the workplace to adopt similar attitudes and behaviours, leading to an increased focus on and awareness of safety among followers. Thus the captain's authentic leadership may lead crew to attending to safety signals in their day-to-day work, which should lead to experiencing fewer unwanted incidents. Our results showed that crewmembers with a captain that provided more authentic leadership performed fewer unsafe actions (H3) and had more accurate situation awareness (H4).

1.5. Aims, approach, and hypotheses of the current study

The aim of the current study was to replicate the findings from our previous study (Authors, 2017). While it is common for research to provide further tests of previously identified relationships, they often do so while using different settings for data collection, different measures, or different analytical approaches (i.e., they are conceptual replications, Yong, 2012). Such approaches do not allow us to say what conditions need to be in place for a phenomenon to be produced. There may be disputes when conceptual replications produce opposing results, and authors with vested interests may be tempted to claim that positive results provide replication support, while negative results can be discounted as being due to methodological differences. Direct replications, on the other hand (Simons, 2014), aim to test previously identified relationships in a way that is as similar as possible to the previous study. This allows us to state with more confidence whether a phenomenon is reliable, allows us to separate a true phenomenon from methodological or contextual artefacts, and advances the scientific discourse.

We made similar data collections in 2015 and 2017 as we did in 2013 (Sætrevik & Hystad, 2017) for vessels on hire for the same company, which allows us to do a full or partial replication of the previous study. Note that the three datasets come from overlapping samples but that responses cannot be linked between the datasets (i.e., they are not longitudinal measures). A successful replication of our previous study (Sætrevik & Hystad, 2017) would demonstrate the robustness of the claim that accurate situation awareness has a crucial role for risk and safety behaviour. Achieving robust knowledge about such relationships could guide applied safety management work. If situation awareness is shown to be crucial, safety management should focus on monitoring and improving employees' situation awareness. This could be done by establishing and implementing company-wide situation awareness measures and developing training programs aimed at improving situation awareness.

In order to provide transparency, to show that the various analysis choices were not informed by the data (Gelman & Loken, 2013) and that the researcher's degrees of freedom were not exploited (Simmons, Nelson, & Simonsohn, 2011), studies should be preregistered when possible. This implies that we provide a description of the planned study in as much detail as possible that is timestamped ahead of data collection or analysis. We made a preregistration of the replication analyses on Open Science Framework (OSF; https://osf.io/36x7a), which described the hypotheses, data collection, analysis plan, and inference criteria for the 2015 and 2017 datasets. At the time of registration, the 2015 dataset had been collected and subjected to various descriptive analyses, but the relationships described in the registration had not been tested. The 2017 dataset was in the process of being collected at that time but had not been compiled to a data file. The safety surveys varied somewhat from year to year due to practical concerns and changes in our industry partner's safety emphasis. This resulted in authentic leadership not being measured in 2017.

The following preregistered hypotheses will be tested, which correspond to the hypotheses in the previous study (Sætrevik & Hystad, 2017): "Situation awareness" will be negatively associated with "unsafe actions" (H1). "Situation awareness" will be negatively associated with "subjective risk assessment" (H2). "Authentic leadership" will be negatively associated with "unsafe actions" (H3). "Authentic leadership" will be positively associated with "situation awareness" (H4). A visual presentation of the relationship between the hypotheses can be seen in **Figure 1** in the Results section.

2. Methods

2.1. Data collection

The 2015 and 2017 data were collected in same way as in the to-be-replicated data collection from 2013 (Sætrevik & Hystad, 2017). A survey booklet written in Norwegian was distributed to all employees of operating maritime vessels that were on hire for a single hydrocarbon energy company operating in the Norwegian Continental Shelf. The crewmembers returned the surveys directly to the researchers individually or through the company mail. Data were collected as part of an energy company's internal health, safety, and environment program. Participation was anonymous and voluntary, and it involved written informed consent. The use of the data for research purposes was in compliance with local ethical guidelines. Note that the three datasets are from overlapping samples but are not longitudinally measured.

Since the actual number of crewmembers per vessel varied from shift to shift and was unknowable to the researchers, each vessel received enough surveys for

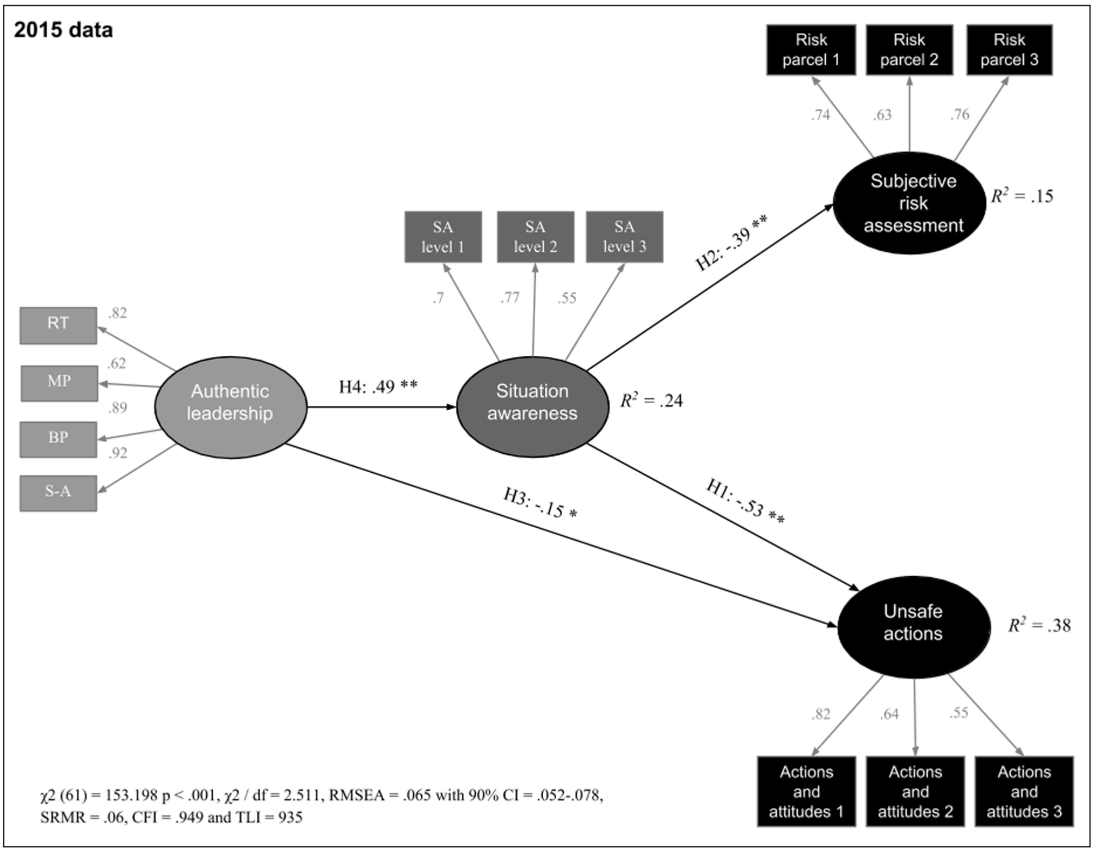

Figure 1: Standardized coefficients for the preregistered structural model on the 2015 dataset. Factor loadings marked with ** are significant at p < 0.001, while the H3 association marked with * is significant at p = 0.02 (one-tailed).

the maximum number of crewmembers. In 2015, the surveys were distributed to 37 vessels, with 30 surveys going to each vessel. There were 448 surveys with valid responses returned from 27 of the vessels. If we assume that each vessel has a crew of 25 (divided in two shifts), the response rate for the vessels that participated is 68%. In accordance with preregistration, we removed 39 participants that reported non-Nordic nationalities or failed to report their nationality, resulting in 409 participants. The responses from 34 captains were removed. This was because the crewmembers were asked to assess their captains, while the captains were asked to assess their own leadership styles. The captains' own assessment of their leadership styles would be caused by different mechanisms than the crewmembers' assessment of their captain's leadership.[1] The final 2015 sample thus consists of 371 participants.

The 2017 data collection was done in the same way as in 2013 and 2015 but with separate survey forms for captains. There were 565 valid surveys returned from 34 vessels, which resulted in a response rate of 66% when estimated in the same way as above. In accordance with the preregistration, we removed 44 surveys where the respondents stated a non-Nordic nationality or failed to answer the question, retaining 521 participants. To maintain similarity with the 2013 and 2015 analyses, we removed 48 surveys that had used the captain response form, retaining 473 participants. Some demographic information about the samples in the 2013, 2015, and 2017 datasets are provided in **Table 1**.

2.2. Measures in 2015 dataset

The 2015 dataset measured "authentic leadership," "situation awareness," "unsafe actions," and "subjective risk assessment." The former three of these were measured with statements to which responders indicated their agreement on a five-point scale, ranging from 1 = *completely disagree* to 5 = *completely agree*.

Like in 2013, "authentic leadership" was measured with the 16-item "Authentic leadership questionnaire" (ALQ, Walumbwa et al., 2008), which had been translated to Norwegian (Borgersen et al., 2014; Nielsen, Eid, Mearns, & Larsson, 2013). ALQ measures the following four components of authentic leadership: relational transparency (e.g., "My leader admits mistakes when they are made"); moral perspective (e.g., "My leader demonstrates beliefs that are consistent with actions"); balanced processing (e.g., "My leader listens carefully to different points of view before coming to conclusions"); and self-awareness (e.g., "My leader shows that he or she understands how specific actions impact others"). Cronbach's alpha for "authentic leadership" in the 2015 dataset was 0.934.

In all three datasets "situation awareness" was measured with the 13-item "context-general situation awareness" scale (see Sætrevik, 2013, for validation of the scale). This scale was designed to measure "situation awareness" across different work settings according to the three levels of Endsley's (1995) model. Four of the items reflect level 1 situation awareness (perception, e.g., "I sometimes lose track of safety due to receiving too much information at

Table 1: Demographic information about the 2015 and 2017 datasets. The 2013 dataset from the replicated study (Sætrevik & Hystad, 2017) is included for comparison.

	2013 dataset	2015 dataset	2017 dataset
Nordic nationality	92.5%	88.9%	92.2%
Age over 35 years	52.7%	49.3%	57.6%
Over 5 years of experience	31.2%	36.8%	59.1%
Supply vessel	66.5%	57.9%	61.2%
Emergency preparedness vessel	20.4%	27.5%	24.5%
Anchor handling vessel	11.2%	13.6%	14.3%
Bridge	30.6%	30.7%	28.5%
Deck	34.3%	36%	35%
Engine room	28%	28.3%	29.3%
Permanent employment	85.6%	87%	82.1%

the same time"); five of the items reflect level 2 situation awareness (understanding, e.g., "I know which situations in my work involve higher risk than others"); and the last four items reflect level 3 situation awareness (projection, e.g., "I plan ahead in order to handle various adverse incidents that may arise"). Cronbach's alpha was 0.759 for "situation awareness" in the 2015 dataset.

"Unsafe actions" was measured with the same seven items as in the 2013 dataset. The items described actions that could increase the likelihood of accidents or actions that conflict with safety procedures. The items were "I have exposed myself or others to danger in order to get the job done"; "Safety is not the most important aspect of my work"; "To get the job done, I have taken shortcuts with regards to safety"; "Safety procedures often stand in the way of getting the job done effectively"; "I sometimes adapt my work to avoid triggering certain safety procedures"; "It is acceptable for me to take chances if I am the only person at risk"; and "I'm sometimes pressured to do work tasks that I know may reduce safety." Cronbach's alpha was 0.765 for "unsafe actions" in the 2015 dataset.

"Subjective risk assessment" was measured with the same seven items as in 2013. Participants were asked to estimate the likelihood for being exposed to each of the following incidents over the next 12 months, using a seven-point scale going from 1 = *no risk* to 6 = *a large risk*: "Squeeze or crush"; "stab or cut"; "poisoning or gas"; "fall to sea"; "fall on board the vessel"; "electricity, fire or explosion"; and "lift or crane." The classifications of different types of accidents were taken from a reporting system used by the Norwegian Maritime Authority (2011). In accordance with the preregistration, an additional type of accident (not measured in 2013) was included for "major vessel accident." Cronbach's alpha was 0.821 for "subjective risk assessment" in the 2015 dataset.

2.3. Measures in 2017 dataset

The 2017 dataset measured "situation awareness," "unsafe actions," and "subjective risk assessment." "Authentic leadership" was not measured; therefore, the variable was not included in the statistical models of this dataset.

"Situation awareness" was measured the same way as in 2013 and 2015. Cronbach's alpha was 0.786 for "situation awareness" in the 2017 dataset.

In accordance with the preregistration, "unsafe actions" was measured with the same seven items as in 2015 and three additional items: "I urge colleagues to stop work that I believe is being carried out in a risky way" (scores reversed), "I stop work if I think it may be dangerous for me or others to continue" (reversed), and "I do not have enough time to use the safety tools properly." The two former items are taken from the Brief NORSCI scale (Nielsen, Eid, Hystad, Saetrevik, & Saus, 2013), while the last item was suggested by our industry partners. Cronbach's alpha was 0.821 for "unsafe actions" in the 2017 dataset.

"Subjective risk assessment," which was measured in 2013 and 2015 by asking about different accident types, was instead measured with two novel items in 2017, one about being injured in general, "How large is the risk that you may be injured at work for the next 12 months?" and one item about major accidents, "How large is the risk that you may be exposed to a major vessel accident in the next 12 months?" The correlation between these two items was $r = 0.57$ in the 2017 dataset.

See the full item text for all variables in all three datasets in the OSF folder (https://osf.io/bcu6f/). The supplementary materials (sections 2.5 and 2.6) also describe the parcellation of "unsafe actions" and "subjective risk assessment."

2.4. Statistical analyses

Structural equation modelling (SEM) with maximum likelihood estimation on complete data was used to test our hypotheses. As authentic leadership was not measured in 2017, H3 and H4 will only be tested in the 2015 dataset. In addition to the preregistered analysis model, we will explore various adjustments to the statistical models and indices of the variables, some of which were anticipated in the preregistration. As different measures were used in 2015 and 2017, and the two datasets are expected to have partially overlapping samples, the two datasets will be analysed separately. The OSF folder (https://osf.io/bcu6f) contains the surveys, item text for each variable, datasets, analysis syntax, and output.

As a first step, we conducted confirmatory factor analyses (CFA) to establish and verify the structural validity of the measurement portion of the proposed models (Byrne, 2013). Sub-scale mean scores were used as indicators for the latent "authentic leadership" and "situation awareness" variables. For the latent variables "unsafe actions" and "subjective risk assessment," we formed items parcels to be used as indicators. Based on the recommendations of Bandalos and Finney (2001), we formed three parcels each for "unsafe actions" and "subjective risk assessment" by combining items with the highest level of congruence. This was achieved by principal component analyses fixed to extract three factors using varimax rotation (see factor content in sections 2.5 and 2.6 of the supplemental materials that are available in the project folder: https://osf.io/bcu6f).

After establishing adequate fit for the measurement models, we proceeded to assess the full structural models and examine the hypothesized relationships. Model fit was judged by examining the magnitude and statistical significance of factor loadings and a series of commonly used goodness-of-fit statistics. Specifically, to assess model fit, we used the comparative fit index (CFI), the Tucker-Lewis index (TLI), the standardized root mean square residual (SRMR), and the root mean square error of approximation (RMSEA) along with its 90% confidence interval. The chi-square measure of absolute fit is known to be overly sensitive and often signals statistically significant misfit even for trivial departures from perfect fit (Kelloway, 1995). A normed $\chi 2$, defined as the $\chi 2$ divided by df, is often used instead due to the sensitivity of the $\chi 2$ to sample size. All analyses were performed using Stata version 16.1.

3. Results

3.1. Measurement model for 2015 dataset

The structural model described "authentic leadership" as being associated with "situation awareness" and "unsafe actions" and "situation awareness" as being associated with "unsafe actions" and "subjective risk." Running a CFA that allowed all latent variables to correlate demonstrated a good fit for the measurement part of our model ($\chi 2$ (59) = 136.793, $p < 0.001$, $\chi 2$ / df = 2.319, RMSEA = 0.061 with 90% CI = 0.047–0.074, CFI = 0.955, SRMR = 0.051, and TLI = 941). To confirm that our latent factors are independent constructs, we compared the four-factor model with a one-factor model where a single latent factor accounted for all indicators. The one-factor model did not fit the data well ($\chi 2$ (65) = 684, $p < 0.001$, $\chi 2$/df = 10.529, RMSEA = 0.163 with 90% CI = 0.152–0.175, CFI = 0.644, SRMR = 0.136, and TLI = 0.572), and had higher AIC (9799.845) and BIC (9951.185) values than the four-factor model (AIC = 9264.277 and BIC = 9438.901). See **Table 2** for a correlation matrix between the variables in the structural model.

3.2. Preregistered latent variable model for 2015 dataset

The preregistered structural model for the 2015 dataset (see **Figure 1** below) tested H1, H2, H3, and H4 as similarly as possible to the test performed on the 2013 dataset (Sætrevik & Hystad, 2017). The model showed good fit indices. Further, the model fit, factor loadings, and explained variance were similar to the 2013 data, thus indicating a replication of these findings. There were medium to strong associations from "situation awareness" to "unsafe actions" (supporting H1) and to "subjective risk assessment" (supporting H2) and from "authentic leadership" to SA (supporting H4), while the association from "authentic leadership" to "unsafe actions" was weaker (partially supporting H3). The model accounted for large amounts of the variance for all three latent variables. In terms of indirect effects, there were statistically significant ($p < 0.001$) effects both of "authentic leadership" on "unsafe actions" via "situation awareness" (b = –0.32, β = –0.26) and of "authentic leadership" on "subjective risk assessment" via "situation awareness" (b = –0.16, β = –18). See **Table 3** for a correlation matrix between the variables in the structural model.

Table 3: Correlation matrix of the variables involved in the analytical model for the 2017 dataset. All shown correlations are significant at $p < 0.001$.

	Situation awareness	Subjective risk	Unsafe actions
Situation awareness	1		
Subjective risk	–0.2200**	1	
Unsafe actions	–0.3940**	0.2555**	1

Table 2: Correlation matrix of the variables involved in the analytical model for the 2015 dataset. All shown correlations are significant at $p < 0.001$.

	Authentic leadership	Situation awareness	Subjective risk	Unsafe actions
Authentic leadership	1			
Situation awareness	0.3290**	1		
Subjective risk	–0.1079**	–0.2484**	1	
Unsafe actions	–0.3021**	–0.4224**	0.2147**	1

3.3. Measurement model for 2017 dataset

The structural model described "situation awareness" as being associated with "unsafe actions" and "subjective risk." A CFA that allowed the three latent variables to correlate showed good fit for the measurement part of our model ($\chi2$ (17) = 34.675 p = 0.007, $\chi2$ / df = 2.04, RMSEA = 0.048 with 90% CI = 0.024–0.071, SRMR = 0.032, CFI = 0.983, and TLI = 0.972). In contrast, a one-factor model with a single latent factor accounting for all the indicators did not fit the data well ($\chi2$ (20) = 371.606 p < 0.001, $\chi2$ / df = 18.58, RMSEA = 0.197 with 90% CI = 0.180–0.215, SRMR = 0.112, CFI = 0.659, and TLI = 0.523) and had higher AIC (7664.731) and BIC (7763.459) values than the three-factor model (AIC = 7333.8 and BIC = 7444.87).

3.4. Preregistered latent variable model for 2017 dataset

The preregistered structural model for the 2017 dataset included tests for H1 and H2, while H3 and H4 could not be tested in this dataset, as "authentic leadership" was not measured in 2017. The model found support for both the H1 and H2 (see results in **Figure 2** below), which showed that "situation awareness" was strongly associated with having fewer "unsafe actions" and somewhat weaker associated with "subjective risk assessment." The model accounted for large amounts of the variation in "unsafe actions" and a medium to large amount of variation in "subjective risk assessment."

3.5. Additional analyses

The preregistered analyses of the 2015 and 2017 data described above show acceptable fit indices, confirm the hypotheses being tested, and account for considerable amounts of the variation. Nevertheless, additional analyses were run to test adjusted statistical models. Some of these were anticipated in the preregistration, while others were more exploratory. These are further discussed in sections 3.6–3.11 in the supplementary materials that are available in the project folder (https://osf.io/bcu6f). The tested relationships were also significant after the variable indices (removing from "unsafe actions" three items that could be said to be more related to attitudes, adding items related to risk for crew to "subjective risk assessment," and including non-Nordic crewmembers in the sample). The project folder contains data, syntax, and results for both preregistered and additional analyses to allow interested readers to explore these further.

4. Discussion

4.1. Summary of results

The overall structural model and all the preregistered hypotheses were supported, and all models showed acceptable model fit. The test of the 2015 dataset thus replicated the full model from the 2013 dataset (testing H1, H2, H3, and H4), and the test of the 2017 dataset replicated parts of the model (testing H1 and H2). There was strong support for the association of "situation awareness"

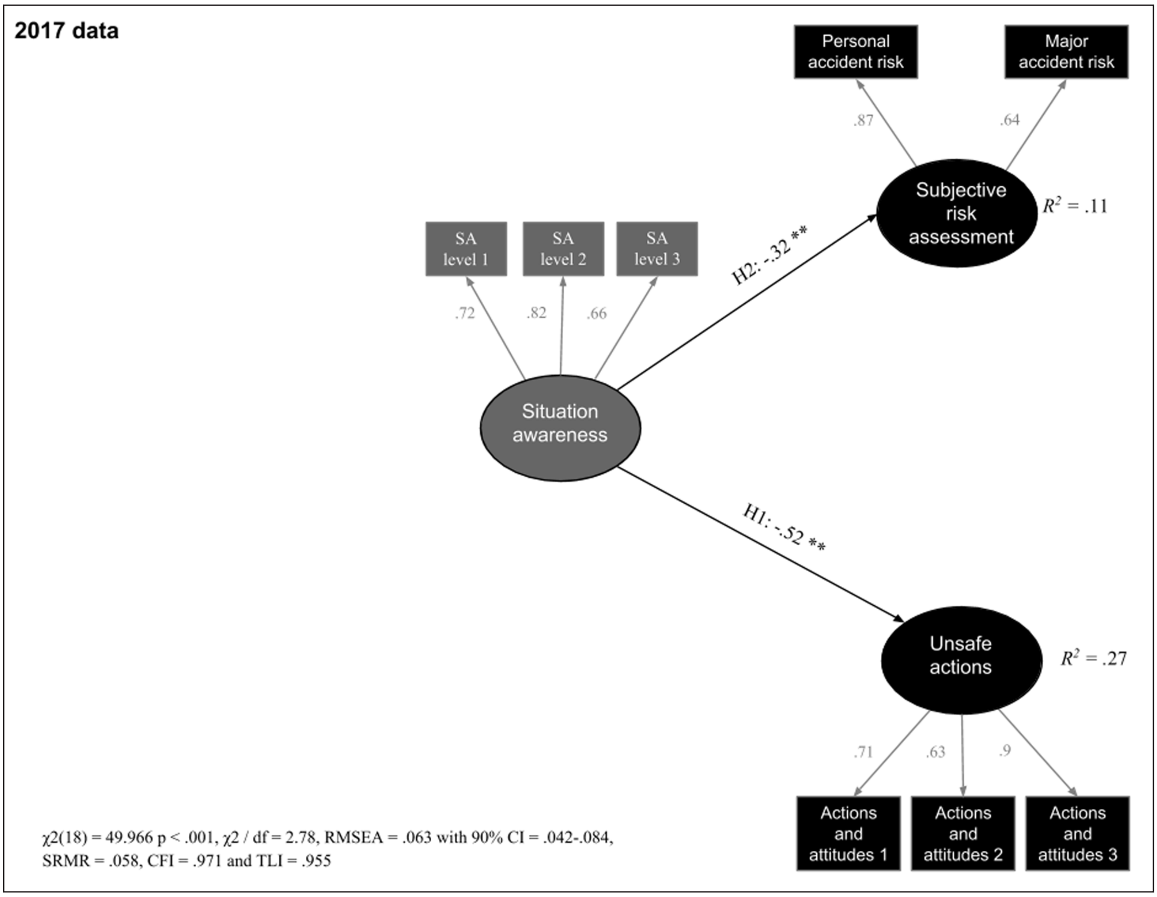

Figure 2: Standardized coefficients for the preregistered structural model on the 2017 dataset. Both factor loadings are marked with ** to indicate significance at p < 0.001.

to "unsafe actions" and to "subjective risk assessment" (H1 and H2, both tested across both datasets), accounting for a large amount of variance in "unsafe actions" and medium to large amounts of variance in "subjective risk assessment." Further, there was also strong support for the association between "authentic leadership" and "situation awareness," which accounted for a large amount of the variance (H4, tested only in the 2015 dataset). There was moderate support for the association between "authentic leadership" and "unsafe actions" (H3, tested only in the 2015 dataset).

4.2. Assessment of replication

The preregistered analyses replicated the same results as in the previously published study (Sætrevik & Hystad, 2017) for all four hypotheses in the 2015 dataset and for the two hypotheses that were tested in the 2017 dataset. This lends support to the original findings by indicating that the same relationships of similar magnitudes could be found when applying the same measurement and analyses on similar samples two and four years later. The results were replicated despite some changes in how the two outcome variables were measured in the new datasets. Further, the preregistered approach demonstrated that the replication was not due to ad hoc hypothesizing or by exploiting researcher degrees of freedom.

The "unsafe actions" items used in the analysis of the 2013 dataset and in the preregistered models included some items that were not strictly related to actions performed by the crewmember. Based on a review of face validity in the preregistration, these items were removed in follow-up analyses (available as supplementary online materials). As the results were largely unchanged while validity could be argued to be improved, we recommend removing these items for future analyses. Future measurement should also make sure that all items in fact describe actions that the crewmember is responsible for, as opposed to actions that they are encouraged by others to perform, actions that are generally accepted among the crew, or actions that are performed by the crew in general but not necessarily by the responder themselves. Another additional analysis (available in supplementary materials) also indicated that model fit could be improved by adding questions about "risk for other crewmembers" to the "subjective risk assessment" measure in the 2015 and 2017 analyses.

4.3. Mechanisms for leadership and awareness to impact safety

The current study indicates that associations that were previously identified (Sætrevik & Hystad, 2017) between "authentic leadership," "situation awareness," "subjective risk assessment," and "unsafe actions" appear to be reliable and replicable for the current setting. The preregistered statistical models explained a large amount of the variance in the safety outcomes. This could indicate that the concepts of authentic leadership and situation awareness are important for regulating risk in safety-critical organizations. This is in line with recent research indicating the primacy of mental models for maintaining safety and how intrapersonal interaction supports the operator's work to construct accurate mental models (Hystad et al., 2014; Mathieu, Heffner, Goodwin, Salas, & Cannon-Bowers, 2000; Nielsen, Eid, Mearns, et al., 2013).

Crewmembers' self-report of situation awareness was found to be associated with and accounted for variation in risk assessment and committing unsafe actions in both the 2015 and the 2017 datasets, comparable to the effects that were seen in the 2013 dataset. A high score on the situation awareness measure indicates that crewmembers state to have accurate representation of the safety-critical aspects of their work. Accurate representations entail that the operator notice signals for increased risk (level 1 situation awareness). According to Endsley's model (Endsley, 2004, 2015), accurate representation further entails that the operator incorporates risk factors in a complex understanding of their work environment and can recognize situations of increased risk where caution must be heeded (level 2 situation awareness). Finally, accurate representation would allow the operator to anticipate dangerous situations and to facilitate decision-making in safety-critical operations (level 3 situation awareness). Situation awareness could thus facilitate safe behaviour, leading to fewer reports of unwanted incidents (Endsley, 1995; Sneddon, Mearns, & Flin, 2006b). Further, situation awareness implies better perception, understanding, and prediction of safety factors, which may be associated with seeing the work as less volatile and more controllable, which may lead to seeing the risk as being lower (Kass, Cole, & Stanny, 2007; Sandhåland et al., 2017).

Crewmembers' perception of the captain's authentic leadership was found to be associated with situation awareness (only tested in the 2015 dataset). The association accounted for large amounts of the variation in situation awareness. Authentic leadership was also associated with committing fewer unsafe actions, although this association was somewhat weaker. These effects of authentic leadership in the 2015 dataset were replicated from the 2013 dataset. These findings indicate that the leadership style of the immediate leader impacts the individual worker's cognitive states and actions (Burke, Fiore, & Salas, 2003; Dionne, Sayama, Hao, & Bush, 2010; Murase, Carter, DeChurch, & Marks, 2014). Although no worker wants to have inaccurate mental models or to perform unsafe actions in their day-to-day work, these concerns are weighed against other tasks, goals, concerns, and distractions. An authentic leader may provide information and guidance, be an example, and provide motivation for the follower to pay attention to and to understand the safety-critical aspects of their work and to comply with the safety regulations.

Previous research has also pointed to the important role of leadership in facilitating the development of accurate mental models (see, e.g., Marks, Zaccaro, & Mathieu, 2000). Bass (1985) has shown that leaders who emphasize authentic means and inspire workers through having a shared vision promote positive safety outcomes through aligning the followers' value systems with the safety values of the organization. This could happen through social mechanisms such as demonstrating individualized considerations, acting as a role model, and inspiring optimism or enthusiasm and through psychological mechanisms of identifying with the leader and workgroup. Clarke (2013) argued that such types of leadership led to increased employee participation in safety, while an active transactional leadership focused on monitoring behaviour. Anticipating and preventing errors from developing could increase compliance with rules and regulations.

It is noteworthy that we measured "subjective risk assessment" differently between the three datasets. The concept nevertheless takes the same role in the structural models tested, with largely overlapping findings. This indicates a coherence between the different measures of risk assessment, which may reflect shared underlying factors.

While our theoretical model tested associations between the measured variables, some of the potential associations were not assumed to be meaningfully related. In the 2013 and 2015 datasets, we tested whether the captain's leadership was associated with workplace behaviour. However, as it had no grounding in past literature, we did not assume that leadership should directly impact the crew's perceived risk of the workplace. Further, as risk assessment and unsafe actions were both measured by self-report at the same time and may have response overlap, we did not expect to be able to discern meaningful causal mechanisms between them in the current studies and thus had no hypotheses about a relationship between them.

4.4. Limitations and extensions

A fundamental limitation of this kind of research is that since both predictor and outcome variables were measured at the same time using the same approach (as opposed to, e.g., longitudinal designs), the results may be influenced by a common method bias (Podsakoff, MacKenzie, Lee, & Podsakoff, 2003). The identified associations may thus partially be due to other factors than reflecting the assumed underlying relationship between the variables (such as the crewmember's positive and optimistic mindset on the day of answering the survey leading to responding that the captain is authentic, that their situation awareness is accurate, that they see the work as safe, and that they seldom violate the safety procedures). Similar criticism could be raised for a significant portion of survey-based research. The current findings should seek support from additional studies that use other measurement approaches, such as measuring at different time points or using multiple types of measures.

In an extension of this limitation, we should note that the "unsafe actions" variable did not rely on objective measures of actions performed but on the crew's self-report of their typical behaviour patterns. Such self-reports are subject to misremembering or misrepresenting the safety of one's behaviour. Further, respondents compare their behaviour to their idiosyncratic safety standards, which may differ between responders and from the optimal safety standard. An objective measure of behaviour in terms of process measures or observer ratings would be preferable but unfeasible for samples of this size.

The current studies do not use one of the traditional measures of situation awareness (Patrick & Morgan, 2010; Rousseau, Tremblay, Banbury, Breton, & Guitouni, 2010; Sætrevik & Eid, 2014), where it is measured in relation to performing a specific task or training exercise. Our conception of situation awareness as a trait concept that can be measured with self-reporting across time and situations may thus only partially overlap with traditional uses of the term. Nevertheless, we argue elsewhere (Sætrevik, 2013) that some aspects of the concept may be trait dependent and that the measures have a theoretical overlap. Further, the traditional measures of situation awareness would not be feasible for studies of this type and extent.

Our samples were all from the same work context, same nationality, and on hire for the same contractor. This limits the generalization of the study, and the identified relationships should seek support from more divergent samples. More specifically, maritime vessels operating in the Norwegian hydrocarbon industry are subject to strict government regulations and industry guidelines, and safety management and information campaigns have improved the safety standard over the past decades. This is likely to affect the crewmembers' actions, attitudes, and perceived norms and thus influence their responses in the study. This should be taken into consideration when generalizing from this study to other settings that are less strictly regulated.

Finally, the current study and the replicated study found correlational associations from which we can argue there may be underlying causal mechanisms. However, experimental designs should be applied before we can assert that the associations are due to causal mechanisms. This could take the form of field-intervention studies that measure safety levels before and after implementation (e.g., training programs aimed at modifying the captain's leadership style or assisting the workers' ability to understand safety aspects in their environment).

4.5. Conclusion and implications

The current study found that the previously reported associations (Sætrevik & Hystad, 2017) between authentic leadership, situation awareness, risk assessment, and unsafe actions could be replicated in two additional similar datasets. Since the participants in the samples are likely to overlap, this should not be considered as two independent replications in different populations, but rather as replicating the same findings twice more in the same population at different times using slightly varying measures. Preregistration of the analyses ensures that the researcher's degrees of freedom were not exploited to replicate the results. The results indicate that the concepts of authentic leadership and situation awareness are relevant for assessing safety levels on vessels and that they may be involved in the social and cognitive mechanisms that are relevant for safety. Similar results may be expected from other populations in safety-critical industries (or high-reliability organizations), where there is an emphasis on compliance to safety regulations. The current results further indicate that the self-report measure of situation awareness has meaningful associations with other safety variables and can thus be of value to include in future survey studies. We thus recommend that similar approaches can be used to assess safety levels or to identify features suitable for interventions to improve safety.

The associations that are now found in three similar datasets indicate the central role of authentic leadership and situation awareness in determining workplace safety. This should motivate safety-conscious companies to attend to how the closest leaders can encourage and model safety and how workers can become more in control of the safety aspects in their work. If either of these features are found lacking, the organization should apply interventions to improve them.

Previous studies have indicated that there may be strong individual dispositions for authentic leadership (such as emotional intelligence, see Miao, Humphrey, & Qian, 2018). Yet, there is also evidence that the authentic leadership capacities can be increased through training and targeted interventions (e.g., Corriveau, 2020; Frasier, 2019), which has led researchers to argue that most people have the potential to become authentic leaders (Baron & Parent, 2015). Because learning authentic leadership would imply internalizing certain attitudes and behaviours, to be effective, initiatives should rely less on traditional teaching methods such as theory-based lectures, and more on the individual's lived experience. Both Baron (2012) and Corriveau (2020) provide evidence that an experimental learning approach containing elements such as simulation, trigger events, peer feedback, and coaching can bear fruit.

Training programs have also been found to be effective for developing situation awareness for complex tasks. Computerized training modules have been found to improve pilots' decision-making (Bolstad, Endsley, Costello, & Howell, 2010). Emphasis shift training combined with situation awareness training was found to increase diagnostic performance in process control (Burkolter, Kluge, Sauer, & Ritzmann, 2010). Virtual environment training has been shown to be effective in training the situation awareness of teams of industrial operators (Nazir, Sorensen, Øvergård, & Manca, 2015). Situation awareness training of police students led to better performance and lower mental workload in a shooting simulator (Saus et al., 2010). Simulator training of naval navigation has indicated that individual personality differences may determine how personnel benefit from SA training (Saus, Johnsen, Eid, & Thayer, 2012). A review of different training programs (Walshe, Crowley, O'Brien, Browne, & Hegarty, 2019) found the improvement to health care professionals' situation awareness outcomes to be moderately larger with simulation-based training than with other approaches.

These studies indicate that training can improve both leadership and situation awareness in technological, complex, and team-based safety-critical workplaces. As the current study indicates a crucial role for these concepts, organisations that emphasize safety should focus on attending to these issues.

Note

[1] Note that it was not specified in the preregistration how to handle the responses from the captains in the 2015 data collection. In the 2013 survey, the captains evaluated the leadership style of their immediate leader in the organization. Since our hypotheses concerned the captain's leadership, the responses from the captains were excluded from the analysis.

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Competing Interests

The authors have no competing interests to declare.

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