Safety culture and worker fatigue management in the offshore oil and gas industry: An interview study

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ABSTRACT

Multiple incidents in the offshore oil and gas industry have been associated with poor safety culture. Regular assessments of safety culture among operators and contractors is recommended as part of a safety management system. Poor safety culture has also shown to impact how operators manage offshore hazards, such as worker fatigue. Assessing workers' fatigue states is also critical to ensure safety in the offshore oil industry. This paper describes findings from an interview study that aimed to identify current safety culture assessment and worker fatigue management practices in the offshore oil and gas industry. One-hour virtual semi-structured interviews were conducted with eighteen offshore oil rig supervisors. Various state-of-the-art methods for assessing safety culture (e.g., experience sampling method) and worker fatigue (e.g., physiological sensors and psychomotor vigilance test) were introduced to the participants. Participants commented on the feasibility and potential barriers to implementation/administration of the various methods, as well as how the information might be useful in their supervisory decisions. User expectations for a safety dashboard displaying data from such tools and user requirements for such a dashboard were elicited. In addition, participants completed a modified technology readiness and acceptance model questionnaire to assess participants' readiness levels and perceived usefulness of a safety dashboard. The interview results revealed a mixed understanding of what safety culture is and opinions about safety culture measurements. Participants indicated that efforts to manage fatigue currently relied solely on supervisors' observation and workers' self-reports. Participants' opinions about the new assessment methods varied. Some were supportive and commented that the new methods will be helpful to improve supervisory-level decisions, whereas others pointed out potential compliance issues.

1. Introduction

Offshore oil and gas rigs are high-risk, complex work environments (Mathisen et al., 2022). Exposure to chemicals, noise, physical and cognitive stressors, and mechanical and electrical hazards in offshore rigs can result in injuries and fatalities to workers (Knegtering and Pasman, 2009). Moreover, hazards of major spills, fires, and explosions can also lead to property and environmental damage (Tang et al., 2018). Incidents in the offshore environments are associated with not only exploration, storage, and processing of oil and gas products, but also harsh working environments and transportation (Broni-Bediako and

Amorin, 2010). There is a critical need to identify effective and practical risk management and incident prevention methods specific to offshore environments. In this work, we are interested in promoting offshore work safety through two important aspects: safety culture and worker fatigue management.

Safety culture has shown to be a critical factor for risk management and a strong predictor of risky behavior in the offshore industry (Adie et al., 2005). According to the Bureau of Safety and Environmental Enforcement (BSEE), safety culture is "the core values and behaviors of all members of an organization that reflect a commitment to conduct business in a manner that protects people and the environment" (BSEE,

2013). Although it is recommended that organizations should measure safety culture regularly (National Academies of Sciences, Engineering, and Medicine, 2016), the optimal frequency of safety culture measurement is largely unknown. Most researchers measure safety culture through lengthy, infrequent (annual), one-time surveys (Payne and He, 2021).

In this project, we chose to measure safety culture using state-of-the-art experience sampling methods (ESM). ESM refers to techniques that capture individuals' daily experiences shortly after they occur (Beal, 2015). These techniques involve collecting data from individuals daily or multiple times throughout the day to obtain the lived, day-to-day experience of workers (Gabriel et al., 2019). One advantage of ESM over traditional surveys is the reduction of memory biases because it requires less recall of prior experiences. Modern handheld computing devices like smartphones and tablets have made it possible and convenient to administer surveys and gather ratings much more frequently. However, the feasibility and practicality of frequent assessments with handheld devices in the offshore environment are unknown.

A potential contributor to safety culture is fatigue, which is also a critical factor for incident prevention in the offshore environment (Sneddon et al., 2013). Fatigue is generally defined as a physiological state of reduced mental or physical performance capability resulting from sleep loss, circadian phase, and workload (International Civil Aviation Organization, 2012). In the offshore oil and gas industry, a hitch (duration of continued work period in the offshore environment) typically varies from 14 days to 28 days. Workers are exposed to long work hours, intense workload, and changing shift patterns which can lead to elevated fatigue levels (Shortz et al., 2017). With advances in sensor technology in recent years, a variety of unobtrusive wearable devices are now available to continuously monitor workers' physiology (Mehta et al., 2017). In this study, we were interested in several methods that have shown promise including wrist-worn actigraph devices to collect sleep quality information (Riethmeister et al., 2019; Zhu et al., 2017) and the Psychomotor Vigilance Test (PVT) to measure vigilance (Ferris et al., 2021; Riethmeister et al., 2018). However, the practicality of implementing such technologies as well as acceptance levels among rig workers is unknown.

The objective of this study was to conduct semi-structured interviews with rig supervisors to ascertain (a) the current practices of safety culture and fatigue management in the offshore oil and gas industry, (b) the feasibility of implementing ESM methods for safety culture assessment, and (c) perspectives on fatigue monitoring in the offshore environment, and in particular using wrist-worn sensors and vigilance tests. The interviews were conducted as part of a larger project where the ultimate goal is to design a safety dashboard that presents the data collected using various new methods including daily safety culture assessments as well as wrist-worn sensors and PVT to monitor worker fatigue. Therefore, the secondary objectives of this research were (d) to elicit expectations for a safety dashboard that provided fatigue and safety culture information, and (e) to investigate readiness levels and perceived usefulness of such dashboard.

2. Material and methods

2.1. Participants

Semi-structured interviews were conducted with participants who had experience as offshore rig supervisors. The study was advertised via email to various offshore groups and during relevant conferences in the United States. Eighteen participants were recruited using snowball sampling and word of mouth and were compensated with a $100 electronic gift card. The study was approved by the Texas A&M University Institutional Review Board (IRB 2020-0311 M).

2.2. Data collection

A semi-structured interview protocol was designed to assess current efforts to measure safety culture and manage worker fatigue, reactions to the proposed new methods to measure safety culture and worker fatigue, and expectations concerning a safety dashboard that presents corresponding data. A set of 12 items to assess safety culture on a daily basis were generated and shared with participants (Appendix A). Author SP developed this survey with items mapping to BSEE's definition of the nine safety culture characteristics (BSEE, 2013), with the intent of trying to capture the extent to which an individual worker experienced these characteristics on a given workday. Items were adapted or abbreviated from Beus et al., (2019). The full interview protocol which introduces participants to actigraphy and PVT methods is provided in Appendix B. This interview protocol was drafted by authors XW and FS through several iterations, and was discussed with and edited by authors RM, SP, and a domain expert on the research team. Technology readiness and acceptance were assessed with previously validated instruments (Davis, 1989; Parasuraman and Colby, 2015) to obtain participants' general attitudes about technology, and expected acceptance of the safety dashboard. Participants were asked to fill out the Technology Readiness and Acceptance Model (TRAM) questionnaire (Lin et al., 2007) which combines readiness and acceptance constructs at the end of the interview. Appendix C shows the detailed questions of the questionnaire. Fig. 1 presents an overview of the key topics and example questions covered in the interview protocol.

Authors FS (an associate professor of industrial engineering) and XW (a postdoctoral fellow), both experienced with qualitative methods, conducted the interviews. The interviewers did not have prior knowledge of the participants. The interviews were conducted virtually via Zoom (Zoom Video Communications, 2020) and Microsoft Teams (Microsoft, 2020) during June 2020–September 2021. Each interview took around 1 h. The audios from the interviews were recorded and transcribed using Otter.ai (2020). Two undergraduate students edited the transcripts to remove any errors. Due to the nature of semi-structured interviews, not every question was asked and not every question received a response.

2.3. Data analysis

Author XW and one graduate student with prior qualitative analysis experience analyzed the interview data using thematic analysis (Guest et al., 2012). The two coders reviewed the transcripts independently. Then they met to discuss the codes and build a consensus. XW completed a second round of coding to make sure it was complete and consistent. For interview studies, the sample size needed to reach saturation varies across studies (Fusch and Ness, 2015). Two commonly used approaches are: (1) through analysis, when no new information is found, with further confirmation of additional two participants, and (2) initial target to be selected based on studies of similar nature (Saunders et al., 2018). In the current study, we took the first approach, and decided that saturation was reached since the last five interviews did not produce additional themes.

3. Results

3.1. Demographics

A total of eighteen participants were recruited. All of the participants were male. Table 1 summarizes age, tenure in the industry, tenure as supervisor, and current job title for each participant. Two participants (No. 1 and 13) formerly worked on rigs and at the time of the interview served as consultants for safety auditing services, and the other 16 participants were currently employed by one of three drilling companies approached during recruitment. Participants' tenure in the offshore oil and gas industry ranged from seven to 44 years ($M = 20$, $SD = 10.8$);
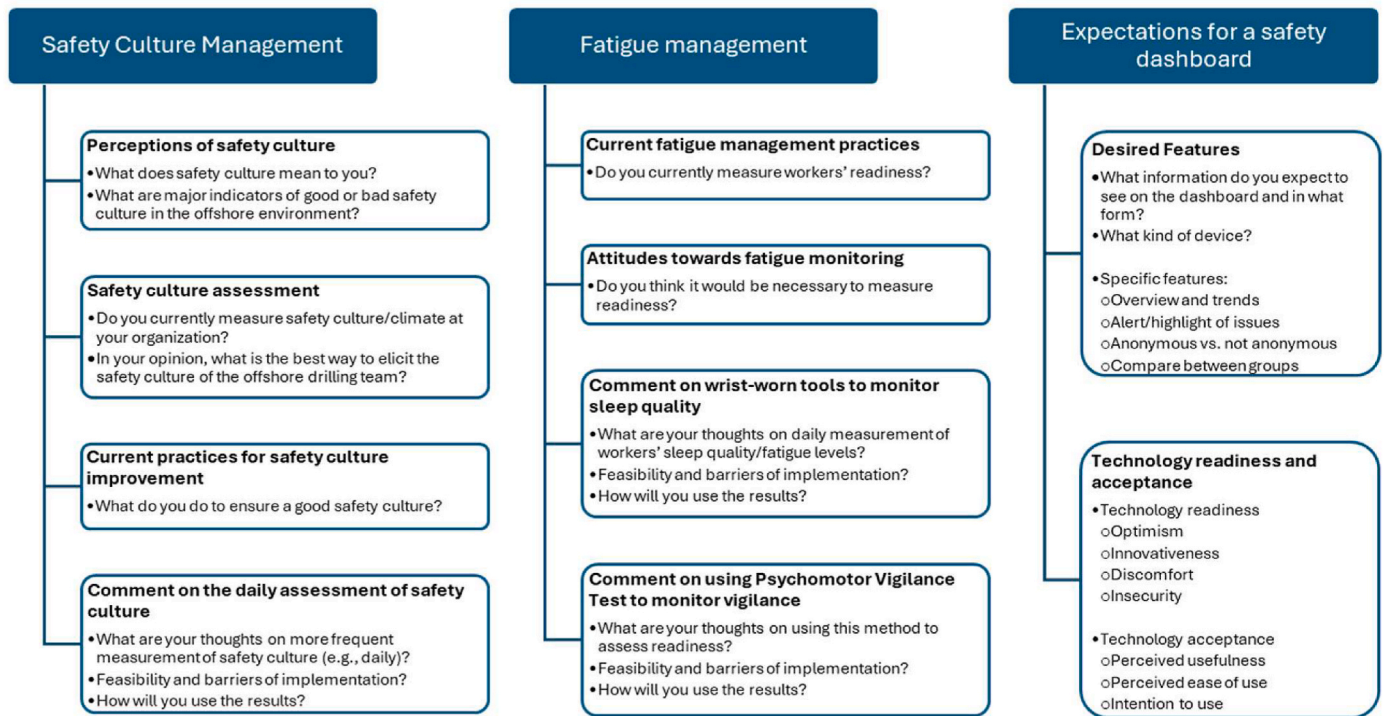
Fig. 1. Overview of the key topics and example questions.

Table 1
Overview of participants' characteristics.

Participant No.	Age	Tenure in the Industry (years)	Tenure as Supervisor (years)	Current Job Title
1	63	44	43	Consultant (used to be Offshore Installation Manager)
2	49	26	16	Rig Manager
3	37	9	6	Senior Electrical Technician
4	43	25	11	Rig Welder
5	41	12	11	Electrical Supervisor
6	34	8	8	Technical Section Leader
7	33	7	3	Safety Officer
8	37	9	9	Assistant Technical Section Leader
9	41	17	15	Subsea Supervisor
10	41	23	16	Drilling Section Leader
11	52	33	33	Deck Supervisor
12	40	18	15	Health, Safety & Environment (HSE) Director for the Western Hemisphere
13	56	38	28	Consultant (used to be Drilling Manager)
14	40	21	7	Senior Subsea Engineer
15	39	19	11	Tool Pusher
16	34	7	3.5	Chief Mate
17	50	25	20	Senior Mechanic
18	50	19.5	15	Tool Pusher

tenure as supervisor ranged from three to 43 years ($M = 15$, $SD = 10.5$).

3.2. Safety culture management

Table 2 presents a summary of the key themes identified through the qualitative analysis regarding safety culture related questions. Here, only themes mentioned by three or more participants were listed for conciseness. The following sections describe the complete details with participant quotes as examples.

3.2.1. Perceptions of safety culture

Participants were asked to describe their understanding of safety culture. Eight participants indicated that to them safety culture is simply no one gets hurt and no incidents. Seven participants mentioned organizational beliefs and behaviors (e.g., "buy-in from everyone on the rig") as the key characteristic of a 'culture'. Four participants mentioned using proper tools/PPE and following the procedures. Four participants indicated that to them safety culture is mainly the relationship between supervisors and workers. Four participants mentioned "safety over productivity." Three participants associated safety culture with how comfortable people are to stop an unsafe job. One participant described safety culture as how much the ground truth ("what our supervisors want us to do") reflects the official truth ("what the company wants us to do").

> *"Everybody looks out for each other. If we see any hazards along any task that we do, we're not afraid to stop the job. Safety's always put over productivity. Never in a hurry. Management never hurries us. So, I've got a pretty good safety culture out here." –P3*

> *"It means that the environment the people who are involved in … have developed a mature sense of safety and understanding what their authority and their rights are with safety and they exercise them freely without reservation. That to me is a well-matured safety culture." -P13*

Participants were also asked what they thought were indicators of good or poor safety culture. A majority of participants (15/18) mentioned whether workers follow standard procedures as an indicator. Eight participants mentioned the relationship among workers, or whether workers are comfortable to stop an unsafe job. Five participants mentioned number of incidents. Three participants mentioned that supervisors' attitudes about new safety policies can be an indicator.

> *"It starts at the top! So having the supervisors really buy into it is a big way to tell what kind of safety culture you're going to have. Because if, for example, someone up there that's over the drilling side doesn't believe in*

Table 2
Summary of findings regarding safety culture management.

Category	Theme	Sub-theme	n[a]
Perceptions of safety culture	Understanding of safety culture	• No hurt, no incident	8
		• Organizational beliefs and behaviors	7
		• Using proper tools/PPE, following standard procedures	4
		• Relationship between supervisors and workers	4
		• Safety over productivity	4
		• How comfortable workers are to stop unsafe job	3
	Major indicators of good or bad safety culture	• Whether workers follow standard procedures	15
		• Whether workers are comfortable to stop unsafe job	8
		• Number of incidents	5
		• Supervisors' buy-in on new safety policies	3
Safety culture assessment	Current practice of safety culture assessment in the organization	• No safety culture measure	3
		• Other (For details see Table 3)	
	Best way to measure safety culture	• Observation in the field	13
		• Safety performance records	4
Current practices for safety culture improvement	Current practice to ensure a good safety culture	• Emphasizing "stop the job"	9
		• Emphasizing standard procedures	6
		• Encourage workers to think about hazards	5
		• Lead with real examples	3
		• Engagement between shore base and offshore	3
Comment on the daily assessment of safety culture	Thoughts on more frequent measurement of safety culture	• Beneficial	7
		• Not necessary to be frequent	3
	Feasibility and barriers to implementation	• Potential poor compliance	6
		• Potential low data quality	5
		• Potential fake positive data	4
		• Feasible (no barrier)	4
	Suggested frequency	• Weekly	6
		• Daily	4

[a] n indicates the number of participants (out of 18) who mentioned the theme.

what we're doing, or the safety side of maybe a new policy that is rolled out then you can't expect this guy to follow it, because he's not going to pass it on or not really sell it to them that, hey, this is how we're going to operate. So, the attitude of supervisors is a big one for safety culture. Because if my boss doesn't care about it, why should I?" –P7

Two participants associated safety culture with whether the work area is clean or messy. Two participants mentioned that a good indicator is whether people think about hazards before performing a job.

"The key and the good indicator is when you see somebody doesn't just run in and try to do a job. They take a few minutes to look around and see what dangers are around, what could happen, and try to make sure you don't do things that way. And bad indicators, I think is just running in and doing a job without thinking what could go wrong, who could this affect, what equipment could get torn up by doing this." –P4

Table 3
Summary of main themes for measurement of safety culture.

Name	Description	Number of Participants
STAR card (behavior-based safety program)	One card completed by each worker each day to describe an observation of a good or bad safety-related behavior	7
Third-party audit	Third-party consultants conduct an audit on the rig	4
Home audit	Self-check and prepare for the third-party audit	3
Work site verification	Supervisors pick certain jobs and ask questions about the job	3
Permit-to-work audit	An audit where supervisors observe permitted work and go through a checklist of criteria	2
Task-based risk assessment (TBRA)	A procedure in which the team involved in a task discuss and document identified hazards and what needs to be done to ensure safe operations	2
STOP program	When an unsafe condition is observed, it is stopped, corrected, and reported in an electronic system	2
Records	Records of injuries, incidents, near misses	2
Rig visits	Higher management visit rigs to strengthen leadership commitment or management engagement	1
Management by walking around (MBWA)	Management walking around near to the crews initiating conversations with them	1

One participant mentioned that the quality of reporting and paperwork, not the quantity, reflects safety culture. Similarly, another participant mentioned covering up in reporting as an indicator.

"You can usually track the quality of the reporting. That will say a lot. How well are the procedures, job safety analysis, risk assessments, how well are they written?" –P13

"Well, first and foremost be the amount of incidents and that's not only to say that there are a lot of incidents on board. But also, if you see that there are no incidents on board. I mean things happen. There's a lot of equipment … you're going to have some operational downtime; you're going to have an immersed hydraulic hose here and there. So, to never see any sort of recording coming from certain installation, you look at that as if they have something to hide." –P2

3.2.2. Safety culture assessment

Participants were asked whether their organization measures safety culture. Responses included various methods, tools or safety initiatives or programs (Table 3). No safety culture-specific instruments were mentioned.

Three participants indicated that there is no safety measure in their organization, or at least no quantitative measure. One participant indicated that a combination of all the safety programs is an indication of safety culture. One participant suggested that the mandatory STAR card program has resulted in low quality data and suggested the program should be optional. One participant estimated that eight out of ten companies in the industry use some combination of the methods referring to several listed in Table 3, while two out of ten, usually the smaller companies, do not require or initiate the methods, but supervisors would institute some strategies to ensure safety.

Participants were then asked what they thought was the best way to measure safety culture. Most participants (13/18) thought that the best way is to stay on the rig to observe and experience.

"Oil and gas companies often hire me to go look at a rig that they're about to pick up and see how I feel about their culture. And that's how I feel it's not much of their KPIs. When you step foot on a rig and spend a couple of

days out there with the people, the atmosphere speaks volumes. You can feel the tension if it's there between supervisors and the workers. And if that's there, we have a real problem. Because our workers don't feel safe, speaking to their bosses, and if you can't communicate, you are not going to have an effective solid sound safety culture. You don't … I don't know how you capture that in a KPI. Do you? –P1

Four participants thought that the safety performance records are the best measure.

"Your record speaks for yourself. Every rig should be held to the same standard and the reporting should be standardized, too." –P10

One participant said talking to junior crew members would be an effective way, to see "if they feel empowered to stop the job without any repercussions." Another participant emphasized that just observing is not enough; one must work with the crew to "pick up on different feelings or emotions." Yet another participant mentioned that the combination of all the safety performance measures will show the culture.

3.2.3. Current practices for safety culture improvement

Participants were asked how they currently ensure a good safety culture. Half of the participants (9/18) mentioned trying to make people comfortable to stop an unsafe job, slow down, or ask questions. Six participants indicated that they make sure people follow standard procedures. Five participants said they encourage people to think about potential hazards before acting. Three participants indicated that it is important to lead with real examples (e.g., talk about a previous fatality as consequence of not following the proper protocol).

"Where we talk about safety, we don't just preach it per se, like force them that you will do this, you will do that; we provide context. In every safety statement, we provide either a lesson learned from another facility and injury that happened because they didn't follow a certain safety protocol. So, we really take the time to make sure everybody understands why these rules are in place. And that there is, you know, history that has caused some of these rules to be written … We talked about, like lockout tagout, why do we lock a piece of machinery before we work on it. It seems like a routine task to some people, maybe they just have a quick job to do. And they think, oh, I don't need to lock it out. But when we put it in perspective, where even recently, somebody was killed on some type of electrical machinery with it, they forgot to lock out and somebody energized it while they were touching it. And then, there was a fatality as a result of it, it really brings all that home to some of the guys that just a reminder that … these protocols and procedures are here for a reason. And if we follow them, it's truly there to keep us safe. So just kind of opens their eyes a little bit to think about it from a real-life perspective. –P6

Three participants emphasized the importance of engagement between management at shore base and offshore groups to ensure safety culture.

"We also monitor rig visits from a shore base perspective, which again, is looking at that leadership engagement. How often is our leadership and management from a shore base perspective interacting with and visiting that offshore group, which gives you a little bit of, again, some of that leadership commitment, some of that management engagement type information." –P12

One participant mentioned knowing workers' competency and assigning jobs to competent people is important.

"As far as me, I know my people, so during the jobs, I always assign jobs that they can handle. I'm not going to have a new person get into a complex job that could overwhelm them, where they might go down there and not … lose focus. And they can hurt themselves … so just by knowing my people, I can assign jobs that they're competent in, that they're competent enough to complete." –P5

One participant discussed their attitude toward rewards and mentioned that monetary incentives may induce failures to report. The participant suggested tokens (e.g., "ice chest with the company logo on it") instead of monetary reimbursement.

3.2.4. Comment on the daily assessment of safety culture

Participants were introduced to the idea of assessing safety culture daily through questionnaire (see Appendix A), and then asked to comment on using the method to measure safety culture frequently. Seven participants thought that the method would be beneficial.

"It'd be good to know [workers'] perspective on [safety culture]. Maybe there is something that we need to change; maybe they perceive something that I'm not seeing. So, it would be beneficial." –P9

Three participants thought the method would not be very useful because they did not think that safety culture would change daily or weekly.

"So, the frequency at which I think you have to fill something like this out, is pretty spread out because the culture predominantly isn't going to change, in a week, right? Likely not any moment, but over six months, you might be able to change it to any degree, right? So, changes in these types of things take a really long time. So, I think frequency at which you would want some people to fill this out might be every two to three months or something right just to see if you're trending one way or the other in some of the areas handing it out daily, I don't think does you much benefit, just because culture is something that takes a really long time." –P12

One participant thought that frequent self-reported measurement of safety culture would not add value on top of the current programs. One participant thought the method is more suitable for early team building of compliance, but less useful for a mature team. One participant commented that safety culture survey is more useful for some positions or departments than others.

"In my job, it's not as prevalent as like a roustabout or roughneck … [they are] constantly in more of labor-intensive tasks than I am, so I guess it would be good for them … They would see more unsafe conditions every day, as far as me, you know, working in an office setting, probably, you know, half of three quarters of my day. –P3

When asked about the feasibility of implementing this method in the daily operations, four participants found it feasible. The rest of the participants mentioned some potential barriers of implementing the method. Six participants mentioned that the most salient problem might be compliance issues (e.g., workers dislike or forget to fill out the questionnaire). These participants also mentioned that, based on when the company requires the workers to fill out the questionnaires, this method might take up workers' off time, which may make workers less receptive to the method.

"I feel like it's bad. That's one thing I don't like about this. The industry we work in and I mean just kind of the oil field in general, I've noticed that as time goes on, we're kind of forced and forced and forced into more bureaucracy, bureaucracy and paperwork, and it becomes a burden to an extent. You still have to do your same job duties, but you're forced to fill out more and more and more checklists and paperwork. And yeah, it kind of brings morale and attitudes down." –P14

Five participants thought that if the method is mandated, the data might have low quality (e.g., blank responses, missing data, random choices). Similarly, four participants were concerned that workers may provide positive data that satisfies the management, which leads to biased data.

"I feel like some people just will say or write whatever they think people want them to say or write. So, I can't say everybody would be 100% honest." –P14

Some participants provided suggestions on how to implement the

method. Three participants emphasized that the system should generate feedback so that "everyone can learn from what has happened and not repeat history," and the feedback can encourage participation. Specifically, one participant suggested presenting the results to workers to encourage participation.

"I would carefully give them a scoreboard of some sort. People generally want to know your opinion of how they're doing … Some sort of scoreboard that says all of the reporting we've done … would encourage people to look up and [participate]." –P13

Two participants believed that the survey must be anonymous to ensure honest responses.

"If you want honesty, you know, it will need to be [anonymous] because … most people in our industry, even prior to the pandemic, now much less after the pandemic will be going back into a work environment, that they feel pressured to maintain their job. Obviously, if they were to write anything derogatory, on you know, to the nature of this was not a safe job, they might find yourself not released because of that, but for some other reasons. So, that's why the confidentiality might need to be applied to some level. I'm not exactly sure how you do it, but to be honest, they either have to trust their supervisor, it goes back to like I said, that supervisor that is safety driven. And people can talk to him. Because if they don't have that type of supervisor, they'll be reluctant to be honest on your questionnaire." –P13

Two participants suggested asking details with open-ended questions rather than ratings.

"I wouldn't ask a worker if his leader has demonstrated a commitment to safety. Because they're gonna [nod and say] 'yes'. I would be more specific with the question … How has your supervisor demonstrated to you that he's concerned about your safety and the safety of this rig?" –P1

One participant suggested using some sampling methods, because "it is probably not feasible to have the whole crew do it every day." One participant suggested incorporating the survey into the after-action review.

"I would incorporate your questionnaire in the after-action review format … These questions are very similar to the same type of questions we use during after-action reviews. So if you incorporated it into the after-action review, [it] might be much easier to receive [answers], and much more honesty put into it. Because now it would be a team of people who just performed a job. It's not one person answering your question, so no one can be singled out." -P13

Regarding the frequency of measurement, seven participants indicated that daily measurement is too frequent, while four participants thought daily measurement is beneficial. As for the optimal frequency for the measurement, six participants suggested weekly, one participant suggested once per hitch, and one participant suggested once every two or three months.

"I don't know if daily. Sounds like … a culture thing that wouldn't change daily. 'Putting safety over productivity' and stuff of that nature, that's more of a culture of the rig. It's not really a daily question that changes on a daily basis, in my opinion." –P6

Participants were also asked if they had access to the data collected daily, how they might use the results in their decision-making process. Seven participants indicated that they would like to talk to the individual who marked issues.

"If I had the answers to what everybody had written down that I supervise, and I see that there [are] some things on there that need to be improved, or someone said, they felt like they were rushed, or someone felt like they didn't have the right tools, or someone felt like production was more important than safety, and you know what, that's when we need to take a step back and have a look at things and try to make things right. So

yeah, you could use that definitely to help the, the job out in the future, or for the very next day for that person. So, whatever it is that this person or individual felt like, that was, not toward the good, but more toward the bad, then it's up to us as a team to try to get this right." –P11

Three participants thought that they would only act if they saw pattern or trend in the data (e.g., multiple people over a long period marking issues, compared to one low rating on a single day). Two participants said that they would bring up the issues in the pre-tour meeting or weekly safety meetings and discuss with the crew on how to improve. One participant said he would map the ratings with KPIs and see whether there was a correlation. One participant said he would map the individual's rating with the specific job performed for the day to see how to improve. One participant mentioned that he would not only use the survey results to address issues, but also "congratulate people on the good work each day."

3.3. Fatigue management

Table 4 presents a summary of the key themes identified through the qualitative analysis regarding fatigue management related questions. Here, only themes mentioned by three or more participants were listed for conciseness. The following sections describe the complete details with participant quotes as examples.

3.3.1. Current fatigue management practices

When asked about how worker fatigue was managed currently, the majority of participants (11/18) indicated that management relies merely on supervisors' observation or workers' self-report, and that fatigue is not measured otherwise.

"Not really measured; just supervisors have to pay attention to their guys to see if they're acting tired during the day, or if somebody comes to them and says I'm tired or, stuff like that. I guess fatigue is not really measured or recorded any kind of way. It's just observed." –P3

Three participants mentioned that it is not always easy to identify fatigued workers because they may hide it to not be perceived as weak by others.

"Sometimes guys feel a little intimidated, guys and girls, if they cannot do the same job as the other person's doing, well, then, they may be picked on, they may be labeled as weak. So, hence the reason to hide it really

Table 4
Summary of findings regarding fatigue management.

Category	Theme	Sub-theme	n[a]
Current fatigue management practices	Current fatigue management practice	• Supervisor observation or worker self-report	11
		• Difficulty in identifying fatigued workers	3
Attitudes toward fatigue monitoring	Whether fatigue monitoring is important	• No additional effort needed	6
		• Fatigue is an issue only for the first day	4
Comment on wrist-worn tools to monitor sleep quality	Thoughts on monitoring of sleep quality/fatigue levels through wrist-worn devices	• Hard to intervene for fatigued workers	7
		• Potentially useful	6
		• Not necessary	3
	Feasibility and barriers to implementation	• Not uncomfortable	6
		• Privacy concerns	4
		• Uncomfortable	3
Comment on PVT to monitor vigilance	Thoughts on using PVT to monitor vigilance	• Time consuming and boring	9
		• Potentially useful	7

[a] n indicates the number of participants (out of 18) who mentioned the theme.

well, and just tough it out. And you know, and then finish the shift. And then sometimes you can't see these people tired." –P13

Two participants mentioned that their departments allow some flexibility to manage fatigue due to the nature of the task. For example, the subsea department (P14) requires some on-call work, and thus they allow flexible rest time to compensate, or the maintenance department (P17) can arrange their plan to distribute the physically demanding job through days. One participant mentioned that the U.S. Coast Guard mandates sleep logs, but only for the key licensed personnel (e.g., captain, section leaders). One participant mentioned that in Europe and some other areas, there was a checklist used to manage worker fatigue.

"We do some coaching and training to our supervision or monitoring for fatigue issues … We've worked with our medical providers in those areas kind of develop a checklist, to track how many days they've been offshore, what shifts are they working, any medications, any sleep issues, things of that sort, and we allow our medical providers to review that, we don't actually review it, again from a privacy perspective. And they can give us some feedback at times on, if we potentially have a fatigue issue. And out of the answer to that checklist, they roll up a risk profile for that employee." –P12

3.3.2. Attitudes towards fatigue monitoring

When asked whether they think fatigue monitoring is important, six participants believed there is no need to add additional effort on fatigue monitoring, and workers should manage fatigue themselves. Specifically, one participant mentioned that "a man knows if he slept well or not" so there is no need for measurements; four participants mentioned that 12 h off time should be enough, and workers are responsible for ensuring good sleep and finishing the work; two participants mentioned that it is hard to get a tired worker replaced on rigs.

"I mean, you're off 12 hours a day, every day. And I understand people say, if it's a sports game, they stay up and watch, or if they're having issues at home, and they're up all night talking on the phone or doing something like that, but you're off long enough to get adequate sleep. And it's not like your job where say you call in sick, someone can be there in 15 minutes. We're in the middle of the ocean, it doesn't work that way. So, I don't think it would be useful because if people started saying they're too fatigued to work and getting a day off, well, you're eventually gonna have an entire rig of people staying inside not working. So, I don't see the benefit in it at all." –P7

Four participants believed that "fatigue is not an issue other than the first day"—only on the first day, some workers experience the fatigue of travel, time zone change, or sleep schedule change. One participant mentioned that it could be addressed by keeping the tasks limited during the transition.

"Normally the only times we have issues with personnel, that are fatigued is their first day on board. On pre change date, some of the personnel, they're not allotted hotels to spend the night before they travel to the rig … even if they do come down, and they're staying in the hotel the night before their schedule, maybe they're working nights and they get on board. So, they're getting adjusted, to this different sleep schedule. And I mean, unless it's an urgent operation and we try to keep the task limited. Hold the first couple of days just for the transition over." –P9

One participant believed that the best way to manage fatigue on rigs is to design shifts that ensure enough time to sleep, because it is not very easy to identify fatigue and intervene.

Only two participants thought it is useful to measure worker fatigue. Specifically, one participant thought it would be interesting to track the change in fatigue level throughout the hitch; the other participant thought it would be helpful in analyzing fatigue as a factor related to incidents.

3.3.3. Comment on wrist-worn tools to monitor sleep quality

Participants were shown a picture of an ActiGraph wGT3X-BT watch which has an accelerometer in it and were introduced to the idea of using the watch to measure workers' sleep efficiency or other tools that use heart rate data to assess sleep quality and duration.

Seven participants thought it was hard to decide on the intervention when a worker with low sleep quality was identified.

"I think quality of sleep is something that varies greatly [and it] depends on so much. There are so many different factors that play into that. And in an offshore environment, I mean, you're limited to how many people you have on board, how many skilled personnel you have on each position. So, it's not like you can just say, "Okay, you didn't sleep well last night, we'll call someone else in." You've only got a certain amount of people there. And so, you are kind of stuck." –P2

Similarly, three participants thought fatigue monitoring using wearable tools is not necessary because the current approaches are enough to manage worker fatigue.

"We all have bad night's sleep, but it doesn't affect our day. You can obviously go on and get a couple hours of rest and be fully functional the next day. I feel like it would take multiple days in a row of minimal sleep for you to be fatigued where you can perform your duties. But how would you integrate that to the management? How would this watch and what is reading be integrated, that would make it useful to us on board? We're here to do a job. And yes, I mean, of course, it's good, you want everyone to be in their best condition every day. But that's not reality, people are gonna have bad night's sleep, people are gonna have issues at home, people are gonna have a world of things that can distract them from work. And that doesn't change the fact that work has to go on. So, if a guy had a bad night's sleep, and he was a little more tired than usual, I'm not going to knock them off and send them back to bed, he's gonna have to complete this job as long as he can do it safely. And I'm not, I'm by no means going to put him in a position where he has to put all of his brain power into completing a task. We can do lighter tasks during that day, but at the end of the day, he's back to bed, he needs to be able to get his rest. So, if, you know, if you take one person off watch, because they didn't sleep well, that's going to affect the other people." –P8

On the other hand, six participants thought the sleep measurement using these wearable tools could potentially be useful. Specifically, two of them thought the data would be useful when analyzed together with other data (e.g., mapping between quality of sleep and quality of work); two thought the tool could be useful for people to monitor their own health condition; two thought it would be useful to know if their crew members were not sleeping well.

Participants also commented on the feasibility of using wrist-worn tools to track sleep. Six participants thought it would not be uncomfortable while three participants indicated that the watch might be uncomfortable to wear. Four participants indicated that there might be privacy concerns or Health Insurance Portability and Accountability Act issues. One participant emphasized that the watch should not be made mandatory. One participant said that the drillship rocks and might affect how accurately the movements were recorded by the watch.

Participants were also asked if the data is collected and made available, how they might use the sleep measure in their decision making process. Four participants said they might talk to the fatigued worker about the issue. Three participants said they might let the fatigued worker have some rest or time off. Two participants said that the data might help them identify tired workers who do not speak up. One participant said they might adjust task assignments based on the sleep quality trend. One participant was interested in analyzing whether having sunlight throughout the hitch affects sleep quality. One participant thought the data might help identify people with sleep issues, and treatment (e.g., positive airway pressure treatment) can be provided to the worker.

3.3.4. Comment on using psychomotor vigilance test to monitor vigilance

Participants were introduced to the 10-min Psychomotor Vigilance test (PVT; Basner and Dinges, 2011) – a behavioral alertness test where a stimulus (typically visual) appears and a response (typically a button press) is required from the participants immediately. Participants were shown screenshots of a PVT mobile app (where stimuli are red dots and response is tapping the screen) and were asked about the usefulness and feasibility of conducting pre- or post-shift tests to measure worker alertness. Half of the participants (9/18) were concerned about several barriers that may hinder the usage or effectiveness of the test including the test being time consuming and boring or compliance issues. They also mentioned that the data quality might be low, assuming that workers are forced to complete the test. In addition, two participants thought it was not useful because supervisors should be able to observe whether the workers were ready for work.

"I think people would get tired of it. And they really wouldn't pay that much attention. And you would probably have a lot of results saying that there was nobody fit for work on board the vessel. People's time is precious to them, you know, if they're awake, they want to go to work. They don't want to sit around and doing a test to go to work … I feel like unless people were giving their full effort, and actually focusing on it, that you would have a lot of results that were negative results." –P8

"You know, in the offshore world today with the more and more and more and more training, a lot of training takes place on board … they gonna meet, typically 30 minutes before they go on tour. There'll be another pre-tour meeting. So, they've already gotten been up, brush your teeth, get dressed, eating, and have pre tour meeting and then they go on tour. At the end of their tour, they may have some kind of safety training that they're obligated to do by their company, internal trainings and stuff like that. That's another 10 minutes of their time off. But, and certainly not something that I would institute on a daily basis for all my guys coming out of bed. You know what I mean? Do you know if you had a good night's rest when you wake up in the moment? You know if you've been restless." –P1

On the other hand, seven participants found the PVT to be useful in testing the alertness of workers, though three of whom found it boring; one of whom mentioned that the PVT might be more successful than the wrist-worn tools because the PVT has less privacy issue; one suggested multiple checkpoints throughout the day to track the changes.

Participants were also asked how they might use the PVT data in their decision-making process. Five participants indicated that they might assign tasks based on workers' alertness level (e.g., assign critical tasks to people who were more alert). One participant was interested in monitoring the change in the scores over the hitch and expected the scores to drop. One participant would encourage people who were not focused to get more sleep. One participant thought intervention would only be meaningful when the results show a trend (e.g., a worker having multiple days with low alertness) instead of a single anomaly (e.g., one bad result). Another participant similarly indicated that if there were issues identified by analyzing the data, scheduling changes would be the best intervention. One participant said that the data might help them identify tired workers who do not speak up.

"If in a perfect world, everyone did take it seriously, and you had a guy that was, I would say, maybe not … one day had a bad day, but if he was trending, he was having multiple bad days, and I would use it as a resource that he has something going on, and it needs to be intervened. Maybe he has issues at home, or maybe he's just really not sleeping. I think that and speaking me personally, when I don't sleep out here. It's not because I'm not tired. It's because I have other issues occupying my mind. And for the most part, people that have issues offshore occupying their mind or issues with people on shore. So, I think it would be a good indicator on their mental fitness more than their fatigue, if it would be more if it was a trend, not just a one day … and a certain pattern, then yeah, I

would say it would be a useful tool, then it might just be something that they need to talk about." –P8

3.4. Expectations for a safety dashboard

Participants were asked about their expectations of a dashboard that presents the safety culture and worker fatigue information to help with supervisory-level decision making.

Half of participants (9/18) expected to see group summaries and trends.

"Yeah, I would say that the dashboard if you combined all three of those metrics into one dashboard and allow the supervisors who are planning the work to have access to that and look at the trends, if you have trends going in one direction where several people are getting poor sleep, or they're answering the questions negatively, or the red dot test is showing that their readiness and their fatigue levels or their alertness are falling off, we can use that data to see why that's happening and adjust accordingly." –P6

Eight participants expected the dashboard to show specific information for each individual and highlight issues, so that they could solve the issue.

"I would want to know which one of them is having a problem or having trouble or whatever, so we can help that individual, or even take his testimony, if you will take that and we'll try to help the whole team out. It might be seeing something that we don't." –P11

On the contrary, three participants believed that the dashboard should not show data for individuals. They emphasized that individual data should be anonymous to protect privacy. One participant emphasized that the safety culture data should be anonymous, but the fatigue data can be shown with individual names.

Three participants expected a feature to compare data across different departments, positions, shifts, or experience levels. One participant was interested in seeing the comparison between fatigued and non-fatigued workers.

"You get a wide variety of crafts. You had people that technical side that worked outside all the time. And then you have like, some of the roustabouts that they're younger, they're in their 20s, and all they do is manual labor. And then you got some people that just sit inside. So you'll have to look at the results from each different department and kind of analyze it to say that, okay, that people sitting inside are pretty good, they're not going to get hurt. But these young kids, they might not have that much experience, they might not know that what they're doing is dangerous. And they need to sleep more … and just track the department they work in, and then just see how they're doing. That is because you got some people that just sit inside all day, then you've got some people that work outside during different jobs, but they're in the same group, kind of like track the position they do would be the best one, just to see how that is." -P5

"Everybody's information would be put on a certain trend, and we can see, I don't know whether, you know, bar graph style, or whatever, where you can see how focused somebody was, and compare it to how much sleep they've been getting, and I guess, cross examine it … then you can probably … find a trend where, you know, the ones that were getting proper sleep, were able to focus the extra minutes while they were off work. And those are probably the ones that are more focused outside and able to see not just in their little work bubble, but those around them as well." –P15

Three participants mentioned that the dashboard should clearly define the measures and explain the severity of issues.

"It definitely needs to have clear definition of what this means, for the supervisor to use it … And it can be as in any industry I'm sure these have

been done before. So, data of how this has been handled in other industries and in other places. And that might help them make better decisions." –P2

Two participants mentioned that the dashboard needs to support a high-level, quick overview for higher-level supervisors.

"From a vessel perspective onshore, it gives that management the ability, if they had access to determine if they had any issues, particularly on their location, right, they're more location specific. From where I sit … I'm looking at the whole fleet versus only one muscle. So we need to be, you know, be able to look at from a high level fleet perspective down to a specific location to determine where those issues were, and give management the ability to see that." –P12

"I'm more concerned about who will be the monitor, or who is the manager of such a dashboard. And you know, because you are limited with people, and most of the people have enormous task already to take care of. And if you started to adapt a new dashboard with some new responsibilities for tracking, it almost requires another person to do it. That person couldn't be anyone that you already have on the facility because like I said, in general, everyone is pretty much flat out with everything they have to do already. So it may not be as well received either if it's thrown into someone's responsibilities, and then I already have more than they can handle. The higher-level managers in my perspective have looked at, including myself and in the drilling managers position, I look at very much a, you know, until something goes wrong, I'm looking at a 10,000-foot view. So, I'm looking at the overall performance for safety. How many participate? How many participants are actually participating in the programs? Have we had any accidents? Have we had any near misses? Do we have anything leading us up the triangle to fatality? So, from managers' perspective, a very, very, very quick overview of all of it, which is reported daily, by the way, you have a daily safety reporting method that comes in as well." –P13

Two participants suggested implementing the dashboard on computer screens rather than tablets, because most supervisors work predominantly on personal computers.

One participant expected the dashboard to be "simple, not cluttered." Another wanted to see the analysis of correlation between fatigue and performance. One participant emphasized that the dashboard should not be used to set higher performance standards.

"I guess it all depends on how supervisors intending to use it … I think that in regard to the pressure, one of our crew members gave an example, such as in a warehouse, there're two teams that are working. They said, whoever works the hardest gets a pizza party at the end of the day. But both teams put out, you know, over 100% trying to get, you know, this pizza party. And then the supervisors came back and said, okay, we did this amount of work. And we're going to expect this from here on out. Well, they used it as a study to see how hard people could work and what they're willing to put forth into their work. And now they were setting the expectation levels at that level. Which I don't think it can be used for something like that." –P16

3.5. Technology readiness and acceptance scores

The TRAM results showed that participants were generally optimistic about the effectiveness of administering frequent safety culture measurements as well as using technological interventions for fatigue and alertness monitoring and found the proposed methods useful and easy to use. Participants' reactions toward the optimism and innovativeness dimensions were somewhat positive, their discomfort level was relatively low. However, participants showed some insecurity about reliance on technology. The questionnaire is provided in Appendix C. Table 5 shows the average scores of the TRAM measures.

Table 5
Technology readiness and acceptance scores.

Construct	Measure	Average Score (1–7)	Standard Deviation	Range
Technology Readiness, (Parasuraman and Colby, 2015)	Optimism	5.65	0.76	4.00–7.00
	Innovativeness	4.75	1.07	3.00–6.75
	Discomfort	2.83	0.99	1.50–5.25
	Insecurity	4.94	0.85	3.50–6.25
Technology Acceptance, adapted from (Davis, 1989)	Perceived Usefulness	5.22	0.79	4.00–6.14
	Perceived Ease of Use	5.72	0.90	4.00–7.00
	Intention	5.39	0.85	4.00–7.00

4. Discussion and conclusion

4.1. Key findings

Previous studies recommended that safety culture be measured regularly and more frequently in the oil and gas industry (National Academies of Sciences, Engineering, and Medicine, 2016); however, how frequent it should be is unknown. The feasibility and practicality of implementing frequent safety culture assessments in the offshore environment are also unknown. In our study, most participants found weekly assessments to be feasible. Daily assessment is possible, but barriers were expected including poor compliance or low data quality.

Several fatigue measurement methods have shown utility including wrist-worn actigraph devices to collect sleep quality information (Riethmeister et al., 2019; Zhu et al., 2017) and the PVT to measure vigilance (Ferris et al., 2021; Riethmeister et al., 2018). However, those studies did not investigate the practicality of implementing such technologies as daily routines for offshore rig workers. Our participants showed mixed attitudes toward the necessity of measuring worker fatigue, which could be a critical barrier to the future implementation of any fatigue monitoring programs. Most participants indicated that wrist-worn devices are feasible, with few mentioned potential discomfort and privacy concerns. The 10-min PVT was considered too time-consuming and boring by the majority of participants.

4.2. Frequent safety culture assessment

The interview data revealed that offshore rig supervisors have a mixed understanding of the meaning of safety culture. Some of the participants did not differentiate between safety performance and safety culture, suggesting that a "no hurt, no incident" mindset may be prevalent among offshore supervisors. Indeed, when asked about the current practices of measuring safety culture, some participants mentioned that safety culture is currently not measured, while most described various safety programs that were measuring safety performance rather than culture. While the feedback provided in this study was limited to experiences in several offshore environments in the United States, the findings may suggest an underutilization of safety culture measurement in the industry. This echoes previous findings that the industry lacks an integrative safety performance index, and that safety culture indicators were not well integrated into the index (Tang et al., 2018). First and foremost, the industry needs to agree on the meaning of the construct and a measure before discussing the frequency of assessment.

Offshore supervisors had mixed opinions about the best way to measure safety culture. The majority of participants did not believe that safety culture could be directly measured or believed that the best way to assess safety culture is through observation in the field, rather than self-reported measures; some believed culture can be reflected indirectly by objective records. Safety culture researchers emphasize the perceptual aspect of the construct which means it is necessary to gather individual worker's thoughts and feelings (Zohar, 2014). Although

self-reports are imperfect, they are the most efficient way to measure multiple workers' perspectives.

4.3. Fatigue management through wearable sensors and alertness testing

In general, offshore supervisors in our sample did not use quantitative/objective measures of fatigue. Our findings suggest that the main ways supervisors currently register fatigue levels in their crews are through observations and worker-initiated reporting of fatigue. Despite years of scientific research in healthcare, transportation, and aviation domains which demonstrated that workers' physiological (e.g. fatigue) state is critical to their ability to work safely (Kang et al., 2021; Wagstaff and Lie, 2011), particularly in the offshore industry (Skinner and Reilly, 1989; Sutherland et al., 2016), the majority of supervisors did not perceive fatigue measurement as a valuable safety management approach in offshore environment. Most supervisors believed that workers should be responsible for managing their fatigue themselves. This is in line with previous findings that suggest workers in offshore environments are not asked or required to report fatigue (Mehta et al., 2019). According to our results, a source of resistance to fatigue measurement is limited number of crew members handling offshore operations. Even when a fatigued worker is identified, it will be difficult to decide the proper intervention or to fill in a vacancy. Yet, supervisors who were enthusiastic about wearable sensors and alertness testing offered numerous ways in which the relevant fatigue data could be utilized to manage fatigue levels, ranging from job assignments to modifying sleep schedules.

A few supervisors who believed that fatigue measurements may be beneficial mentioned an important behavioral barrier to implementation of such methods: some workers do not speak up when they are tired because they do not want to "be labeled as weak," a source of self-report bias corroborated by another study (Mehta et al., 2019); both the prior and present study also identified lack of available practical fatigue management solutions as a reason for underreporting fatigue. Interestingly, some supervisors highlighted that the use of objective methods to capturing fatigue levels (e.g., through sensors or tablet-based tasks) could help in circumventing existing safety culture issues, such as those stated earlier.

4.4. Barriers for implementing new methods

An objective of the study was to assess the practicality and perceived effectiveness of several technology-enabled methods of fatigue measurement, including ESM, PVT, and utilization of wearable devices that have shown promise in other domains. While the participants were generally receptive to the technical viability of such methods, a major perceived barrier mentioned was the buy-in from workers and compliance issues due to added workload. Particularly, our evidence suggests that if these methods are mandated, it may negatively impact the quality and reliability of the data. This is in line with previous findings that workers' involvement in decisions is important to safety compliance (Dahl and Olsen, 2013). It is likely better for supervisors to obtain willing compliance through a participative leadership style than requiring participation using an authoritarian leadership style (O'Dea and Flin, 2001).

Whereas the technical efficacy of using wrist-worn Actigraphs and other physiological sensors to monitor sleep has been established for shift workers in various domains including manufacturing (Lin et al., 2016; Park et al., 2000), healthcare (Cheng et al., 2021; Ganesan et al., 2019; Loef et al., 2018), offshore oil and gas (Riethmeister et al., 2019), and sailing (Kerkamm et al., 2022), our evidence suggests that implementation of such methods in the offshore environments may suffer from poor acceptance among workers mainly due to discomfort and privacy concern of sharing health-related data with the company. Such concerns about discomfort and privacy are also well-established in other literature (Moshawrab et al., 2022). However, more work is needed to solicit workers' feedback to verify if supervisors' perception of this barrier is accurate and to identify effective implementation methods to take advantage of benefits provided by such non-intrusive and cost-effective technologies.

Although scientifically, the PVT has been established as a gold standard test to quantify changes in vigilance or alertness associated with fatigue, few studies have documented the feasibility of implementation of the method in the field. Ferris et al. (2021) anticipated that for in-field studies, time, budget, and/or logistical constraints might appear for the 10-min PVT test. Correspondingly, in a field study conducted with emergency responders, participants found the 3-min test to be too long and opted out from completing the test over time (Mehta et al., 2020). In our study, supervisors mentioned similar concerns about worker compliance; however, they conceded that such type of fatigue assessment would be perceived with lower privacy issues than that with wearable sensors.

Despite these documented barriers, our results suggest that supervisors in offshore environments find value in accessing information about workers' safety culture and fatigue on a safety dashboard. However, the supervisors had mixed opinions about what data should be presented on the dashboard particularly the anonymity of the data. Some participants believed that being able to see individual data on the safety dashboard can help them discuss and resolve issues with the individual worker, whereas others emphasized that people will only be honest when the data collection is anonymous. Our interview data suggests that workers in teams with a relatively good safety culture might be more comfortable with identified data in a safety reporting dashboard than teams with a poorer safety culture. The importance of anonymity and confidentiality have been documented by the error reporting literature to ensure that respondents do not answer in a way they presumed was 'correct' or pleasing for the employer (Adjekum et al., 2022; Kongsvik et al., 2012).

4.5. Limitations

There are several noteworthy limitations that may affect the generalizability of the findings presented here. First, whereas the authors are satisfied with saturation for the qualitative findings, recruiting highly specialized roles remains a challenge and therefore the sample size was relatively small, especially for meaningful analysis of quantitative measures such as TRAM. Future work can use other methods such as surveys or questionnaires to elicit feedback from a larger sample and use interviews or focus groups for deeper understanding of identified issues. Second, while we had several participants with a wide range of experience in various offshore rigs, majority of our sample were from three large offshore operators in the United States. Future work may elicit feedback from a wider range of organizations inside and outside the United States to account for cultural differences and operational variabilities. In addition, all our participants were male. Based on 2020 employment survey data (U.S. Bureau of Labor, 2020), only 14.9% of employed persons were female in the oil and gas extraction industry, however it is not clear what percentage of this population serves in supervisory roles. Despite the unbalanced demographics of the industry, efforts should be made to ensure sample data are representative of the population. Third, interviews captured the views and perceptions of those in a supervisory role. Given the known differences between the expectations, perceptions, and experiences of workers at the "sharp-end" and administrative or managerial roles at the "blunt-end" of most complex systems (Mohammed Ashraf et al., 2021), the results may not represent the workers; thus additional research is needed to capture their perspective.

4.6. Conclusion and implications for future work

This work aimed to elicit feedback from supervisors in offshore oil and gas drilling rigs to better understand the efficacy of using frequent

safety culture measurements as well as various technology-enabled fatigue measurement techniques that have shown promise. The findings suggest that despite the prior evidence which clearly shows the benefits of such methods, there is a general gap in understanding and major perceived barriers for implementation of such methods. While difficulties with change implementation and management in offshore work settings are well-documented (Hovden et al., 2008; O'Dea and Flin, 2001), our findings provide preliminary evidence that information provided by these emerging methods may indeed inform better supervisory-level decisions. Participatory ergonomics methods that involve workers in design and implementation of interventions have shown promise in ensuring adoption and sustained compliance and engagement. Future work should also consider integration into well-established workflows and better understanding of current practices and values to inform the design of effective safety management programs.

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CRediT authorship contribution statement

Xiaomei Wang: Writing – original draft, Methodology, Investigation, Formal analysis, Data curation. **Farzan Sasangohar:** Writing – review & editing, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Stephanie Payne:** Writing – review & editing, Supervision, Project administration, Investigation, Funding acquisition, Conceptualization. **Ranjana K. Mehta:** Writing – review & editing, Project administration, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

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Data availability

No data was used for the research described in the article.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ergon.2024.103614.

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