Safety climate and mindful safety practices in the oil and gas industry

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1. Introduction

Over the last three decades the existence of a positive relationship between safety climate and the safety behaviour of employees in high-risk organizations has been confirmed by a large number of studies (e.g. Agnew et al., 2013; Clarke, 2006; Clarke and Ward, 2006; Cooper and Phillips, 2004; Griffin and Neal, 2000; Guo et al., 2016; Sinclair et al., 2010; Thompson et al., 1998). Research within the oil and gas industry is no exception from this (e.g. Dahl et al., 2014). In brief, this body of research demonstrates that employees who perceive that safety is valued and prioritized within their organization display more positive safety behaviour than employees who perceive that their organization places less value on safety.

The well-established empirical relationship between safety climate and safety behaviour has significant theoretical and practical implications. First, it contributes significantly to our understanding of the causal relationship between organizational, social and cultural factors on the one side and human safety behaviour on the other. Second, it demonstrates that variation in safety behaviour is causally related to factors which are in the hands of management. From a practical point of view this is encouraging, because it demonstrates that variation in safety behaviour is not attributable solely to individual psychological variables or chance, but is in fact manageable and susceptible to influence.

Previous studies of the relationship between safety climate and safety behaviour have primarily analysed safety behaviour in terms of safety compliance (adherence to rules and procedures) and safety participation (voluntary efforts to improve safety, such as promoting safety campaigns) (Neal and Griffin, 2004). Both safety compliance and safety participation are important aspects of the human contribution to safety, and several studies have observed a negative causal relationship between these aspects of safety behaviour and the frequency of accidents and injuries (e.g. Christian et al., 2009; Goldenhar et al., 2003; Jiang et al., 2010; Liu et al., 2015). However, research on high reliability organizations (HROs), such as nuclear power plants, naval aircraft carriers and offshore petroleum platforms, has led to emphasis on another type of behaviour that is important to the safe operation of high-risk industries, namely mindful safety practices.

The term ‘mindfulness’ was first introduced to the HRO literature by Weick et al. (1999), but they did not use it to describe an individual’s mental state nor as an extension of the overarching term ‘safety behaviour’. Instead the term was applied to an organizational level characteristic, i.e. an organization’s ability to notice and manage the unexpected and hence Weick et al. preferred the term ‘collective mindfulness’ (see also Weick and Sutcliffe, 2006, 2007).

In the aftermath of Weick et al.’s introduction of the term ‘collective mindfulness’ into the HRO literature, safety researchers have begun to recognize the importance of mindfulness to the individual’s safety behaviour repertoire (Aase et al., 2005; Hopkins, 2002; Reason, 2008). For example, Skjerve (2008, p. 1004) referred to individual mindfulness as ‘mindful safety practices’ and described them as practices where the ‘employee must rely on his or her own ability to be aware of critical factors in the environment and to act appropriately when dangers arise’. Thus, mindful safety practices, which are based on knowledge-based reasoning (to use the terms of Rasmussen, 1983) were contrasted with compliance, which is based on rule-based reasoning. In other words, mindful safety practices are not based on following procedures, but on a ‘subjective, real-time evaluation of the situation at hand’ (Skjerve, 2008, p. 1004).

The objective of this study was to examine whether mindful safety practices, like safety compliance and safety participation, can be promoted by a positive safety climate. To do this we analysed quantitative data on the behaviour of sharp-end workers within the Norwegian oil and gas industry. Research on this topic may yield insight into the broader relationship between safety climate and employees’ safety behaviour. Such insight is believed to be important, not only within the oil and gas industry, but in high-risk industries in general where human behaviour constitutes a vital factor in the safety performance of the organization.

2. Theoretical Background

2.1 Mindfulness and Mindful Safety Practices

The interest in the organizational dimension accelerated in safety science in the late 1980s, supplementing the earlier focus on technical safety and human factors (Hale and Hovden, 1998). The relevance of the organizational level became apparent when investigations into several major accidents (e.g. Chernobyl; Piper Alpha; Texas City) highlighted the role of management, communication and competence and noted that the interaction of such factors was pivotal to the tragic outcome. On a more general level, the interest in organizational factors in the safety field can be seen as a reflection of the increasing complexity in industry, which is related to technological developments, acquisitions and mergers and more integration and couplings of systems, which introduces new vulnerabilities (Rasmussen, 1997; Rosness et al., 2010). Major accidents have been attributed to increasingly complex environments and by deficiencies in the capabilities to adapt to complexity, in line with the classical argument about ‘requisite variety’ (Ashby, 1956). For example, the theory of ‘normal accidents’ (NAT) (Perrow, 1999) regards major accidents as more or less inevitable in socio-technological systems that are both tightly coupled (failures spread fast) and interactively complex (failures spread in unforeseeable ways), such as nuclear power plants, chemical plants, offshore petroleum installations etc.

Another strand of research, developed partly as a response to the fatalistic perspective of NAT, focuses on organizations that seem to have high operational reliability and very few accidents despite being tightly coupled and interactively complex. Identifying the processes underlying this reliability ‘against the odds’ has been an important research area. From the early 1990s, Weick and co-researchers have linked the reliable functioning of organizations to collective mental processes (Weick and Roberts, 1993), arguing that heedfulness arises when the actions of single actors are based on an understanding of how they are related to the actions of others and when actions are collectively aligned. Weick and Roberts (1993) argued that heedful interrelation of actions and mindful comprehension were important preconditions for the safe operation of complex systems such as aircraft carriers. They extended their framework by describing mindfulness in relation to reliability, defined as 'a rich awareness of discriminatory detail' (Weick and Sutcliffe, 2007, p. 32). It was argued that mindfulness was related to five cognitive processes (Weick et al., 1999); (1) Preoccupation with failure i.e. a propensity to treat all failures as signals of potential larger, underlying problems. (2) Reluctance to simplify interpretations. HROs cultivate requisite variety and view simplification as increasing the probability of surprise. (3) Sensitivity to operations i.e. creating awareness about what is really going on; this depends on integration of information from different sources to construct the 'big picture' of ongoing operations, which enables continuous adjustments to be made and can thus prevent errors accumulating in complex systems. (4) Commitment to resilience i.e. the capacity to handle unanticipated dangers successfully and 'bounce back' to a normal state of operations. Resilience implies the ability to cope with surprises and improvise when needed, as well as being prepared for and expecting that something unforeseen might occur. (5) Deference to expertise i.e. accepting that potentially dangerous situations should be handled by the people most competent to do so, independent of their place in the organizational hierarchy. Deference to expertise thus entails a willingness to redistribute power when necessary.

According to Skjerve (2008), collective mindfulness can lead to a certain kind of behaviour. *Mindful safety practices* are safety-promoting work practices that may prevent or interrupt unwanted and unanticipated event sequences (Skjerve, 2008, Aase et al, 2005), for example by warning colleagues if they are in danger or putting work operations on hold if there is uncertainty about safety. Barton and Sutcliffe (2009) underscore that such micro-level social processes are at the core of organizational safety. In their study, voicing concern and creating space for re-evaluation of a chosen course of action was central for maintaining safety. In some instances, mindful safety practices may be incorporated into formal process rules, or made a mandatory part of operations (Hale and Borys, 2013), e.g. evaluation of risk before commencing tasks. However, mindful safety practice includes behaviours and traits that cannot be formalized, such as safety awareness and use of judgment and the ability to respond appropriately to dangerous or potentially dangerous situations. Use of mindful safety practices often implies redundancy, as it involves a control function and different, and sometimes an outside perspective on unfolding events (Skjerve, 2008).

2.2 Safety Climate and Mindful Safety Practices

The safety climate in a work community involves the shared perceptions about safety policies, procedures and practices (Zohar, 2003). The safety climate construct is rooted in the psychometric tradition and questionnaire surveys are often used to provide indications of the culture for safety at a given point in time. There is no consensus on the factorial structure of safety climate, but a review of 18 factorial models of safety climate (Flin et al., 2000) described four underlying themes or factors that are often included in assessments: (1) safety system, (2) work pressure, (3) safety competence and (4) leadership or supervision. The review also identified a fifth factor, risk, but risk is commonly defined and analysed in terms of unsafe or safe behaviour and is, in such instances, not considered an aspect of safety climate (Kvalheim and Dahl, 2016).

Safety climate has been linked to different safety related outcomes, safety performance, and also different subjective attitudes and other work-related issues (Nahrgang et al. 2011). This includes concepts such as job satisfaction and work engagement and also turnover rates

(Huang et al. 2016). A poor safety climate has been considered a stressor that may be associated with physical symptoms and musculoskeletal complaints (Golubovich et al. 2014).

The causal link between safety climate and safety behaviour has frequently been explored, and meta-analyses of the relationship show that variation in safety behaviour can be explained by variation in safety climate. In a review of 32 studies, Clarke (2006) found that safety climate was correlated with both safety compliance and safety participation and a later review of 90 studies (Christian et al., 2009) reported similar associations.

Although many studies have explored the relationship between safety climate and safety compliance and safety participation, there has been no quantitative research directly addressing the association between safety climate and mindful safety practices. A qualitative study by Aase et al. (2005) described some relevant factors, noting, for example, trade-offs between mindful safety practices and staffing levels and time pressure. Work pressure, including the balance between the need to maximize production and safety, is one element of safety climate, which suggests that the two are negatively related. The same qualitative study describes certain formal meetings and tools as important preconditions for the application of mindful safety practices. These meetings and tools, including handover sessions, safety and toolbox meetings etc., can be seen as elements of the safety system. Satisfaction with the various parts of the safety management system is another factor included in many models of safety climate (Flin et al., 2000). The study by Aase et al. thus suggests that there is a positive relationship between perceptions of the safety system and mindful safety practices. Finally, Aase et al. argued that managers' attitudes to safety - which are also a factor in safety climate - are important for the application of mindful safety practices. This indicates a positive relationship between managers' safety prioritization and mindful safety practices. In summary, the qualitative study by Aase et al. (2005) indicates that safety climate is causally related to mindful safety practices. In line with this, and consistent with Flin et al.'s (2000) safety climate factor structure, the present study explored the following hypotheses:

Hypothesis 1: Mindful safety practices are positively predicted by safety system.

Hypothesis 2: Mindful safety practices are negatively predicted by work pressure.

Hypothesis 3: Mindful safety practices are positively predicted by safety competence.

Hypothesis 4: Mindful safety practices are positively predicted by safety leadership.

3. Method

3.1 Data Collection and Sample

The Petroleum Safety Authority Norway (PSA) conducts a biannual, cross-sectional survey of workers in the Norwegian oil and gas industry. The survey data, in combination with other types of data, e.g. accident, near-miss and exposure data, is used to assess health, safety and environmental conditions in the industry. The results contribute to a shared understanding amongst companies, unions and government agencies of risks and inform plans to improve safety and conditions in the industry.

This study is based on the latest available edition (PSA, 2016) of this survey. The original sample consisted of 6 980 respondents from operating, contracting and subcontracting companies, working either on fixed or mobile offshore installations (response rate = 29.7%).[1] To ensure that the final sample consisted only of relevant respondents (sharp end workers) we excluded those working in catering and administration roles[2], leaving a final sample of 5 712 respondents. Respondents with missing values for variables included in our analysis were excluded pairwise. This means that respondents with missing data were included in the analysis, but excluded from calculations for which a data point were missing. Regarding the variables included in the factor analysis, the average missing rate was 1.9%.

[1] This response rate is similar to that in previous PSA surveys, e.g. PSA, 2014.

[2] Respondents who answered 'other' on the work area item were also excluded from the analysis.

The demographic profile of the sample is presented in Table 1. Men made up the majority of the final sample (94.9%); this is broadly representative of the gender distribution of workers on the Norwegian continental shelf (NCS) as a whole (roughly 90% male; PSA, 2012a). The slight overrepresentation of men is due to exclusion of respondents in catering and administration roles. Over a third of respondents (36.6%) reported that they had leadership responsibilities and 13.8% were safety representatives. Most respondents (62.5%) were aged above 40 years and had more than ten years of offshore experience in the oil and gas industry (56.0%). Workers employed on fixed offshore installations constituted the largest group (69.8%), with workers employed on mobile installations making up roughly one third of the sample (30.2%). Overall, the respondents' demographics is consistent with previous surveys on the NCS (e.g. PSA, 2014; 2012b), indicating representativeness.

Table 1
Respondents' demographics.

Characteristics	Per cent
Gender (male)	94.9 %
Leadership responsibility	36.6 %
Safety representative	13.8 %
Age	
≤ 30 years	15.9 %
31-40 years	21.5 %
41-50 years	31.0 %
≥ 51 years	31.5 %
Experience (offshore)	
≤ 5 years	21.1 %
6-10 years	22.9 %
11-19 years	26.7 %
≥ 20 years	29.3 %
Type of installation	
Fixed installation	69.8 %
Mobile installation	30.2 %
N	5 712

3.2 Measures and Statistical Procedures

The survey consists of 175 questions related to demographics, health, working environment, accident risk, safety behaviour and safety evaluations. Based on research on safety climate (Flin et al., 2000) and mindful safety practices (Aase et al., 2005) we selected 19 items to measure safety climate and mindfulness. The initial factor analysis resulted in several cross-loadings when all 19 items were included. A factor structure with no cross-loadings was obtained when 17 of the items were included. Hence, these items were retained in the further analysis. Descriptive statistics for these are presented in Table 2. The items are presented as statements with which the respondents must rate their agreement using a Likert scale ranging from ‘totally agree’ (1) to ‘totally disagree’ (5). There is no ‘don’t know’ or ‘not relevant’ response option.

We carried out exploratory factor analysis (EFA) in the form of principal component analysis with varimax rotation to reduce the number of items to a manageable size and to uncover the underlying factor structure. Factor loadings ≥ 0.40 were considered sufficient to relate each individual item to a factor (Meyers et al., 2006) and the choice of number of factors was based on inspecting the scree plot for a bend point and an assessment of the factor solution with regard to item cross-loadings (Costello and Osborne, 2005). Internal consistency and reliability were assessed with Cronbach’s alpha (Cronbach, 1951).

Table 2
Descriptive statistics for items.

Item		Mean	*SD*
Q1	I think it’s easy to find the right steering documentation	3.27	1.21
Q2	I have easy access to procedures and instructions related to my work	4.22	0.95
Q3	The HSE procedures are suitable for my work tasks	4.21	0.87
Q4	I always know which person within the organization to report to	4.12	1.06
Q5	Sometimes I am forced to work in a way that threatens safety	1.76	1.11
Q6	In practice the production takes precedence over HSE	2.50	1.31
Q7	I experience group pressure which jeopardizes HSE evaluations	1.94	1.12
Q8	Work operations often take place in parallel, which leads to dangerous situations	2.19	1.12
Q9	If I observe dangerous situations I report them	4.72	0.59
Q10	I ask my colleagues to stop working if I think that they are performing their activities in a manner that threatens safety	4.61	0.69
Q11	When I do my job safety has first priority	4.70	0.57
Q12	I have received sufficient work environment training	4.20	0.89
Q13	I have received sufficient safety training	4.47	0.74
Q14	I know the HSE procedures well	4.49	0.72
Q15	I prefer not to discuss HSE conditions with my leader (reverse scored)	4.44	0.92
Q16	My leader welcomes it when I raise topics related to HSE	4.41	0.88
Q17	My leader is committed to working with HSE on the installation	4.37	0.86

We used hierarchical multiple linear regression analysis (ordinary least squares) (Meyers et al., 2006) to test the hypothesized relationships between the independent variables and the dependent variable. The hierarchical procedure means that each hypothesis was tested individually by entering each safety climate factor into the model in separate steps. Assessment of the hypotheses was based on *p*-values and the direction of the regression coefficients (*B*). The significance level was set at $\alpha = 0.05$. In addition to the direction and the *p*-value of each coefficient we also used the standardized regression coefficient, beta (β) to assess the relative effect of each climate factor. The model as a whole was evaluated in terms of percentage of variance accounted for (R^2) and the improvement in variance accounted for at each step (ΔR^2).[3]

4. Analysis and Findings

4.1 Exploratory Factor Analysis

Seventeen items were included in the factor analysis and the sample size was *N* = 5 712. Preliminary analyses confirmed that the data were suitable for factor analysis. Kaiser–Meyer–Olkin's measure of sampling adequacy and Bartlett's test of sphericity produced satisfactory results (see notes for Table 3).

Table 3
Exploratory factor analysis: PCA, Varimax with Kaiser normalization.

Items		Factor loadings					
		1	2	3	4	5	Comm.
Q1	I think it's easy to find the right steering documentation	0.788					0.672
Q2	I have easy access to procedures and instructions related to my work	0.730					0.648
Q3	The HSE procedures are suitable for my work tasks	0.633					0.581
Q4	I always know which person within the organization to report to	0.661					0.557
Q5	Sometimes I am forced to work in a way that threatens safety (rev.)		0.706				0.579
Q6	In practice production takes precedence over HSE (rev.)		0.637				0.560
Q7	I experience group pressure which jeopardizes HSE-evaluations (rev.)		0.673				0.570
Q8	Work operations often take place in parallel, which leads to dangerous situations		0.744				0.601
Q9	If I observe dangerous situations I report them			0.775			0.671
Q10	I ask my colleagues to stop working if I think that they are performing their activities in a manner that threatens safety			0.661			0.508

[3] All analyses were conducted with SPSS version 23.0 software.

Q11	When I do my job, safety has first priority			0.749			0.626
Q12	I have received sufficient work environment training				0.793		0.770
Q13	I have received sufficient safety training				0.791		0.793
Q14	I know the HSE procedures well				0.589		0.555
Q15	I prefer not to discuss HSE conditions with my leader (reversed)					0.570	0.469
Q16	My leader welcomes it when I raise topics related to HSE					0.739	0.711
Q17	My leader is committed to working with HSE on the installation					0.649	0.642
Rotated sum of squared loadings (% of variance)		14.04	13.51	11.71	11.33	11.25	
Eigenvalues (Total)		6.08	1.32	1.27	1.02	0.83	

Bartlett's test of sphericity (approx. Chi-square) = 29393 ($p < .001$). Kaiser-Meyer-Olkin measure of sampling adequacy = 0.914. Factor loadings below 0.40 are suppressed. Rev.: reverse scored.

Inspection of the scree plot suggested a bend at factor 5; however the eigenvalue dropped below 1.00 at factor 5, indicating that a four-factor solution might be more appropriate. The four-factor solution, however, resulted in a complex factor structure with numerous cross-loadings above 0.40. Thus, a five-factor solution was tested. This solution proved satisfactory, consisting of a simple factor structure with no cross-loadings above 0.40 (Table 3). The final five-factor model accounted for 61.8% of the total variance.

The first factor, *safety system*, consisted of four items related to respondents' perception of procedures and the safety management system. After varimax rotation this factor accounted for 14.0% of the variance and the factor loadings varied from 0.633 to 0.788. The second factor, *work pressure*, comprised four items related to respondents' perception of the relative importance of efficiency versus safety, and framework conditions affecting the priority given to safety. After varimax rotation this factor accounted for 13.5% of the variance and the factor loadings varied from 0.637 to 0.744. The third factor, *mindful safety practices*, consisted of three items related to respondents' own mindful safety practices. One of the items was phrased in general terms and asked respondents to evaluate the priority they gave to safety when doing their job; the other items were related to reporting of dangerous situations and confronting colleagues working unsafely. After varimax rotation this factor accounted for 11.7% of the variance and the factor loadings varied from 0.661 to 0.775. The fourth factor, *safety competence*, was made up of three items related to respondents' view of health, safety and environment (HSE) training they had received and their knowledge of HSE procedures. After varimax rotation this factor accounted for 11.3% of the variance and the factor loadings varied from 0.589 to 0.793. The fifth and final factor, *safety leadership*, was made up of three items associated with respondents' perception of their leader's focus on HSE issues. After varimax rotation this factor accounted for 11.3% of the variance and the factor loadings varied from 0.570 to 0.739.

Table 4 presents correlations between factors and values of Cronbach's alpha for each factor. Low or moderate correlations indicate high discriminant validity, whereas high correlations between factors that are supposed to differ indicate low discriminant validity (Netemeyer et al., 2003). As Table 4 shows, all correlations between factors were low or moderate and thus the discriminant validity of the set of items can be considered acceptable.

According to Nunnally (1978), values of Cronbach's alpha greater than 0.70 indicate adequate internal consistency and reliability; however, Cronbach's alpha is not just a function of the correlations between the items, but is also strongly influenced by the number of items contributing to a factor (Cortina, 1993) and so values "... must be interpreted with the number of items in mind" (Cortina, 1993, p. 102). As shown in the diagonal in Table 4, all values of Cronbach's alpha were greater than 0.70, except for *mindful safety practices* (α = 0.68), but given the number of items contributing to this factor this value was considered acceptable.

Table 4
Pearson's correlations between factors; Cronbach's alpha on the diagonal.

Construct	Number of items	1	2	3	4	5
1. Safety system	4	(0.76)				
2. Work pressure	4	-0.48	(0.74)			
3. Mindful safety practices	3	0.39	-0.38	(0.68)		
4. Safety competence	3	0.53	-0.41	0.42	(0.73)	
5. Safety leadership	3	0.51	-0.57	0.49	0.52	(0.72)

All correlations are significant at the $p < 0.01$ level.

4.2 Tests of Hypotheses

The results from the regression analysis are presented in Table 5. The analysis was conducted hierarchically in five different steps (model 1 – model 5), with more predictors added at each step. This allows for individual tests of each safety climate factor. In model 1 three control variables were entered; male, age and experience. In model 2 the first of the four safety climate factors, safety system, was entered. In model 3 the second safety climate factor, work pressure, was entered. In models 4 and 5 respectively, safety competence and safety leadership, the last safety climate factors, were entered into the regression analysis.

Table 5
Linear regression: mindful safety practices with unstandardized (B) and standardized (β) regression coefficients.

	Model 1			Model 2			Model 3			Model 4			Model 5		
	B	β	p	B	β	p	B	β	p	B	β	p	B	β	p
Constant	4.660		**	3.759		**	4.295		**	3.664		**	3.050		**
Male	-.066	-.030	*	-.104	-.047	**	-.083	-.037	*	-.089	-.040	*	-.075	-.034	*
Age 31-40 years	.040	.035		.032	.028		.035	.031		.046	.040	*	.033	.028	
Age 41-50 years	.125	.122	**	.103	.100	**	.089	.087	**	.099	.097	**	.081	.079	**
Age ≥ 51 years	.182	.178	**	.131	.128	**	.106	.104	**	.113	.110	**	.099	.097	**
Exper. 6-10 years	-.027	-.024		-.022	-.019		.001	.001		.001	.001		.002	.002	
Exper. 11-19 years	-.024	-.022		.007	.007		.029	.027		.027	.025		.032	.03	
Exper. ≥ 20 years	-.040	-.038		-.005	-.005		.019	.018		.029	.027		.031	.029	
Safety system				.238	.393	**	.166	.275	**	.101	.167	**	.065	.107	**
Work pressure							-.133	-.245	**	-.105	-.194	**	-.047	-.086	**
Safety competence										.189	.251	**	.130	.173	**
Safety leadership													.201	.298	**
F-value (Δ)	12.137			947.199			294.115			299.128			365.603		
R^2	.016			.169			.214			.258			.307		
Δ R^2	.016			.153			.045			.043			.049		

* $p < 0.001$ **$p < 0.050$

As can be seen in model 1, where the two control variables are entered, gender is significantly related to mindful safety practices. More specifically, men reported a slightly lower level of mindful safety practices than women (the reference category). Furthermore, the results of model 1 indicate that age is partly related to mindful safety practices. On the one side, the group of respondents between the age of 41-50 years and the group of respondents 51 years and above reported a higher level of mindful safety practices than respondents aged 30 years or below (the reference category). On the other side, respondents between the age of 31 and 40 years do not report higher levels of mindful safety practices than the reference category (≤ 30 years). The number of years of offshore experience is not related to mindful safety practices. In summary, the total effect of gender, age and experience is very small; together they accounted for only 1.6% of the variance in mindful safety practices. In other words, gender, age and experience do not add much statistical power in explaining the variation in mindful safety practices.

Introducing safety system in model 2 led to a substantial increase in variance accounted for (an increase in R^2 from 1.6% to 16.9%). As shown in the table, safety system is positively related to mindful safety practices. Hence, the analysis supports hypothesis 1, that safety system is a positive predictor of mindful safety practices. The *B*-value indicates that a one-unit increase in the safety system factor results in a 0.238-unit increase in the mindful safety practices factor; furthermore, the standardized regression coefficient (β) shows that the effect of safety system (0.393) is far more powerful than the effect of the control variables.

The positive effect of safety system on mindful safety practices is reduced in model 3, in which work pressure is entered into the regression analysis. However, the positive effect of safety system is still significant. As expected, work pressure was negatively related to mindful safety practices, and hence hypothesis 2, that mindful safety practices are negatively predicted by work pressure, was supported. Adding work pressure to the model also increased the percentage of variance accounted for, from 16.9% in model 2 to 21.4% in model 3. Furthermore, the *B*-value shows that a one-unit increase in the work pressure factor produces a 0.133-unit decrease in the mindful safety practices factor. The standardized regression coefficient (β) shows that the effect of work pressure (-0.245) is far more powerful than the effect of the control variables, but slightly less powerful than that of safety system.

As shown in model 4, the introduction of safety competence increases the variance accounted for substantially (an increase in R^2 from 21.4% to 25.8%). As shown in the table, safety competence is positively related to mindful safety practices, and thus the result supports hypothesis 3, that safety competence positively predicts mindful safety practices. The *B*-value shows that a one-unit increase in the safety competence factor results in a 0.189-unit increase in the mindful safety practices factor. Furthermore, the standardized regression coefficient (β) shows that the effect of safety competence (0.251) is far more powerful than the effect of the control variables and is also greater than the effects of work pressure (-0.194) and safety system (0.167). The introduction of safety competence reduces the effects of work pressure and safety system, but they still have significant predictive value in the expected direction.

The variance accounted for (R^2) increases from 25.8% to 30.7% when safety leadership is entered into the regression analysis in model 5. As shown in the table, safety leadership is positively related to mindful safety practices and thus this result supports hypothesis 4, that safety leadership positively predicts mindful safety practices. The *B*-value shows that a one-unit increase in the safety leadership factor results in a 0.201-unit increase in the mindful safety practices factor. Furthermore, the standardized regression coefficient (β) shows that the effect of safety leadership (0.298) is far more powerful than the effect of the control variables and is also greater than the effects of safety competence (0.173), work pressure (-0.086) and safety system (0.107). The introduction of safety leadership reduces the effect of all of these factors, but they still have significant predictive value in the expected direction. Hypotheses 1, 2 and 3 are therefore still supported.

In summary, the regression analysis provides support for all four hypotheses. In other words, the results support the hypotheses that mindful safety practices are positively predicted by safety system, safety competence and safety leadership and negatively predicted by work pressure. In addition, when the analysis controls for the effects of the four safety climate factors both gender and age are related to mindful safety practices. Male is negatively related, indicating that men display fewer mindful safety practices than their female colleagues. Age is positively related, however. *B* increases with age across all categories, except the group (31-40 years) nearest the reference group (30 years and younger), indicating that age is positively related to mindful safety practices. Number of years of offshore experience is not related to mindful safety practices.

5. Discussion

5.1 Main Findings and Discussion

Although formal safety routines and physical barriers are important in high risk contexts such as the petroleum industry, human intervention can be crucial when something unexpected occurs or is in progress. The ability to recognize and report possible dangers and stop co-workers and event sequences before control is lost can prevent major accidents.

In this paper, we have explored the degree to which safety climate can promote such mindful safety practices. As hypothesized, we found that various aspects of safety climate were associated with mindful safety practices. In general, the results support the notion that a positive safety climate at organizational level fosters mindful safety practices at individual level, although conclusions about causal relationships based on cross-sectional data must be treated with caution. Nevertheless, our results corroborate what is now quite a robust finding in safety climate research, namely that positive perceptions of safety climate are associated with pro-safety behaviour (see Christian et al., 2009 for a review). On a more general level Griffin and Curcuruto (2016) perceive safety climate as an aspect of organizational context that shapes behaviour through the mediating factors safety motivation and safety knowledge, suggesting a causal mechanism.

The safety climate measure used in this study encompassed the four common themes identified by Flin et al. (2000). All were associated with the dependent variable ‘mindful safety practices’, and together they accounted for roughly 31 % of the variance in mindful safety practices. The strength of the association between these independent variables and mindful safety practices was variable, being greatest in the case of 'safety leadership', followed by 'safety competence', 'safety system' and 'work pressure'.

The role of leadership in safety behaviour has been well documented in previous studies (Lu and Tsai, 2010; Mearns et al., 2001; Zohar, 2003). Leaders on different levels signal the kind of behaviour that is appreciated and rewarded and can promote the sharing of safety information and promulgate appropriate work practices (Bosak et al., 2013; McLain and Jarrell, 2007). The strength of the effect of leadership on mindful safety practices could be due to the fact that these practices are largely based on interaction with co-workers and management, e.g. reporting dangerous situations, asking colleagues to stop hazardous operations. When management is perceived to be committed to safety and to communicate openly about safety issues, it is likely that such practices will be considered important and appropriate.

Skjerve (2008) highlighted some conditions that increase the likelihood of use of mindful safety practices, and the suggestions are consistent with the associations we observed. The first condition is that employees have the *knowledge and skills* needed to identify hazards and intervene if necessary. This depends on appropriate education and training, including in relation to current safety standards. The safety competence factor in our study encompasses perceptions of HSE training and knowledge. The second condition is that it is *possible* for employees to use mindful safety practices. This relates to issues such as time or work pressure, physical arrangements and how the work is organized in general. Our work pressure and safety system factors are both relevant to this condition, as they encompass framework conditions that can hinder or promote mindful safety practices. The demand for efficiency and time pressure can limit the emphasis placed on safety (Kongsvik et al., 2012). Aase et al. (2005) noted that there is a trade-off between mindful safety practices and staffing levels and time pressure. Procedures and rules that are inappropriate to the work being carried out, or perceived as difficult to find and access imply a level of ignorance about the real hazards of operations and are also not conducive to mindful safety practice.

In addition to the significant relationship between safety climate and mindful safety practices, the analysis revealed that the individual-level factors gender and age were related to mindful safety practices. Men reported a lower level of mindful safety practices than women. This result is in line with research by Reason (1997), who claimed that men, particularly young men, have a tendency to optimize the non-functional goals of the task in hand, e.g. to drive fast in pursuit of excitement at the expense of arriving safely. Furthermore, there was a positive, linear relationship between workers' age and declared use of mindful safety practices (however, no significant difference was observed between age group '≤ 30 years' and '31-40 years'). This result is in line with previous research on the relationship between age and safety compliance (Dahl et al., 2014). The fact that years of offshore experience in the job is not related to mindful safety practices indicate that the effect of age is not due to increased experience.

5.2 Implications, Limitations and Further Work

The findings of the present study have both theoretical and practical implications. The study illustrates that broadening the safety behaviour construct to include factors other than safety compliance and safety participation might be useful. Neal and Griffin's (2004) framework was an important starting point for the modelling of safety behaviour; it describes distal (e.g. safety climate) and proximal (e.g. safety knowledge and safety motivation) causes of variation in safety performance (see also Griffin and Neal, 2000). The empirical studies underpinning the framework have operationalized safety behaviour as compliance and participation, a categorization also suggested by Marchand et al. (1998). This way of operationalizing safety behaviour was subsequently adopted by other safety researchers (Griffin and Curcuruto, 2016). Although compliance and participation are undoubtedly important aspects of safety behaviour, increasingly more complex working environments in terms of both technology and organization (Le Coze, 2015) can benefit from other types of behaviours as well. In complex socio-technical systems there is a greater likelihood of unexpected events and interactions between components that are difficult to foresee. It is necessary that such events are handled competently or avoided, which is exactly how mindful safety practices are conceptualized (Aase et al., 2005).

The practical implications of the findings relate to the causal relationship between safety climate and mindful safety practices. The findings clearly illustrate that workers with positive perceptions of the safety climate reported a higher level of mindful safety practices. Moreover, a positive safety climate was characterized by (1) positive evaluations of the safety system, (2) low perceived work pressure, (3) positive evaluations of HSE training and competence and (4) leaders with a high commitment to safety. These findings have positive implications for safety management, because they demonstrate that mindful safety practices can be influenced, and that variations in such practices are not a result of mere chance or individual variations. In other words, mindful safety practices, like safety compliance and safety participation, are susceptible to change. In order to improve safety climate in a direction which is favourable for mindful safety practices, the results demonstrate that it is important to give the fundamental features of safety climate high priority and in particular that of safety leadership. Placing high priority on these areas communicates to workers that safety is valued within the company. Zohar’s (2010) safety climate framework assumes that visible signals that an organization places a high priority on safety indicate to workers that safety practices are expected, supported and rewarded.

Although the findings have important implications some methodological limitations of the study should be borne in mind. First, the analysis is based on self-report measures drawn from a single source and so the results may be subject to social desirability bias (Edwards, 1953) and common methods bias (Podsakoff et al., 2003). It would therefore be valuable if future research were to investigate mindful safety practices using data from other sources, for example, observations of operations. Second, the cross-sectional design makes it difficult to establish the sequential relationships between safety climate and mindful safety practices. In future research use of longitudinal designs should be considered as a means of providing further evidence of causality. Third, the data do not allow for a detailed analysis of the causal processes involved in the relationship between the dependent and the independent variable. Although the analysis demonstrated that mindful safety practices are predicted by safety climate (by examining the direct relationship), it does not offer a complete explanation of the processes involved (based on analysis of possible indirect relationships). In quantitative analyses, this requires consideration of potential mediator variables. In future studies, use of mediation models should be considered as a means of clarifying the nature of the relationship between safety climate and mindful safety practices. This could involve introducing safety knowledge and safety motivation (Neal and Griffin, 2004) as mediator variables. Fourth, the data do not allow for a comparative analysis of mindful safety practices, safety compliance and safety participation. A comparative analysis should be useful, since the three components of safety behaviour could be related differently to the dimensions of safety climate. For example, Kvalheim and Dahl (2016) have found that work pressure is the most important safety climate dimension with regard to explaining variation in safety compliance. However, the present study indicate that work pressure is the least important safety climate dimension with regard to explaining variation in mindful safety practices.

6. Conclusion

Previous studies of high-risk organizations have confirmed the existence of a positive relationship between safety climate and the safety behaviour of sharp-end workers. These studies have primarily analysed safety behaviour in terms of safety compliance and safety participation. The objective of the present study was to examine whether mindful safety practices are, like safety compliance and safety participation, promoted by a positive safety climate. Analysis of quantitative data from sharp-end offshore workers in the Norwegian oil and gas industry demonstrated that a four-factor model of safety climate was highly related to mindful safety practices. The model accounted for roughly 31% of the variance in mindful safety practices. It showed that the most important safety climate factor was safety leadership. Our findings clearly demonstrate that mindful safety practices are highly context-dependent and hence manageable and susceptible to change.

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References

Aase, K., Skjerve, A.B., Rosness, R. (2005). Why good luck has a reason: Mindful practices in offshore oil and gas drilling, in: Gherardi, S., Nicolini, D. (Eds.), The passion for learning and knowing. Proceedings of the 6th international conference on organizational learning and knowledge. University of Trento, Trento.

Agnew, C., Flin, R., Mearns, K. (2013). Patient safety climate and worker safety behaviours in acute hospitals in Scotland. Journal of Safety Research 45, 95-101. http://dx.doi.org/10.1016/j.jsr.2013.01.008.

Ashby, W.R. (1956). An introduction to cybernetics. Chapman & Hall, London.

Barton, M.A., Sutcliffe, K.M. (2009). Overcoming dysfunctional momentum: Organizational safety as a social achievement. Human Relations 62 (9), 1327-1256. https://dx.doi.org/10.1177/0018726709334491.

Bosak, J., Coetsee, W.J., Cullinane, S.-J. (2013). Safety climate dimensions as predictors for risk behavior. Accident Analysis & Prevention 55, 256-264. http://dx.doi.org/10.1016/j.aap.2013.02.022.

Christian, M.S., Bradley, J.C., Wallace, J.C., Burke, M.J. (2009). Workplace safety: A meta-analysis of the roles of person and situation factors. Journal of Applied Psychology 94 (5), 1103-1127. http://dx.doi.org/10.1037/a0016172.

Clarke, S. (2006). The relationship between safety climate and safety performance: A meta-analytic review. Journal of Occupational Health Psychology 11(4), 315-327. http://dx.doi.org/10.1037/1076-8998.11.4.315.

Clarke, S., Ward, K. (2006). The role of leader influence tactics and safety climate in engaging employees' safety participation. Risk Analysis 26 (5), 1175-1185. http://dx.doi.org/10.1111/j.1539-6924.2006.00824.x.

Cooper, M.D., Phillips, R.A. (2004). Exploratory analysis of the safety climate and safety behavior relationship. Journal of Safety Research 35 (5), 497-512. http://dx.doi.org/10.1016/j.jsr.2004.08.004.

Cortina, J.M. (1993). What is coefficient alpha? An examination of theory and applications. Journal of Applied Psychology 78 (1), 98-104. http://dx.doi.org/10.1037/0021-9010.78.1.98.

Costello, A.B., Osborne, J.W. (2005). Best practices in exploratory factor analysis: Four recommendations for getting the most from your analysis. Practical Assessment, Research & Evaluation 10 (7), 1-9.

Cronbach, L.J. (1951). Coefficient alpha and the internal structure of tests. Psychometrika 16, 297-334. http://dx.doi.org/10.1007/BF02310555.

Dahl, Ø., Fenstad, J., Kongsvik, T. (2014). Antecedents of safety-compliant behaviour on offshore service vessels: a multi-factorial approach. Maritime Policy & Management 41 (1), 20-41. http://dx.doi.org/10.1080/03088839.2013.780311.

Edwards, A.L. (1953). The relationship between the judged desirability of a trait and the probability that the trait will be endorsed. Journal of Applied Psychology 37, 90-93. http://dx.doi.org/10.1037/h0058073.

Flin, R., Mearns, K., O'Connor, P., Bryden, R. (2000). Measuring safety climate: identifying the common features. Safety Science 34 (1–3), 177-192. http://dx.doi.org/10.1016/s0925-7535(00)00012-6.

Goldenhar, L.M., Williams, L.J., Swanson, N.G. (2003). Modelling relationships between job stressors and injury and near-miss outcomes for construction labourers. Work & Stress 17 (3), 218-240. http://dx.doi.org/10.1080/02678370310001616144.

Golubovich, J., Chang, C.-H., Eatough, E.M. (2014). Safety climate, hardiness, and musculoskeletal complaints: A mediated moderation model. Applied Ergonomics 45, 757-766. http://dx.doi.org/10.1016/j.apergo.2013.10.008.

Griffin, M.A., Curcuruto, M. (2016). Safety climate in organizations. Annual Review of Organizational Psychology and Organizational Behavior 3, 191-212. http://dx.doi.org/10.1146/annurev-orgpsych-041015-062414.

Griffin, M.A., Neal, A. (2000). Perceptions of safety at work: A framework for linking safety climate to safety performance, knowledge, and motivation. Journal of Occupational Health Psychology 5 (3), 347-358. http://dx.doi.org/10.1037/1076-8998.5.3.347.

Guo, B.H.W., Yiu, T.W., González, V.A. (2016). Predicting safety behavior in the construction industry: Development and test of an integrative model. Safety Science 84, 1-11. http://dx.doi.org/10.1016/j.ssci.2015.11.020.

Hale, A., Borys, D. (2013). Working to rule, or working safely? Part 1: A state of the art review. Safety Science 55, 207-221. http://dx.doi.org/10.1016/j.ssci.2012.05.011.

Hale, A., Hovden, J. (1998). Management and culture: The third age of safety. A review of approaches to organizational aspects of safety, health and environment, in: Williamson, A., Feyer, A.M. (Eds.), Occupational injury: A Selection of papers presented at the occupational injury symposium - Sydney, Australia, February 1996. Exeter, Pergamon, pp. 129-165.

Hopkins, A. (2002). Safety culture, mindfulness and safe behaviour: Converging ideas? Working paper 7. National Centre for OHS Regulation, Canberra.

Huang, Y.-H., Lee, J., McFadden, A.C., Murphy, L. A., Robertson, M., Cheung, J. H., Zohar, D. (2016). Beyond safety outcomes: An investigation of the impact of safety climate on job satisfaction, employee engagement and turnover using social exchange theory as the theoretical framework. Applied Ergonomics 55, 248-257. http://dx.doi.org/10.1016/j.apergo.2015.10.007.

Jiang, L., Yu, G., Li, Y., Li, F. (2010). Perceived colleagues' safety knowledge/behavior and safety performance: Safety climate as a moderator in a multilevel study. Accident Analysis & Prevention 42 (5), 1468-1476. http://dx.doi.org/10.1016/j.aap.2009.08.017.

Kongsvik, T.Ø., Fenstad, J., Wendelborg, C. (2012). Between a rock and a hard place: Accident and near miss reporting on offshore vessels. Safety Science 50 (9), 1839-1846. http://dx.doi.org/10.1016/j.ssci.2012.02.003.

Kvalheim, S.A., Dahl, Ø. (2016). Safety compliance and safety climate: A repeated cross-sectional study in the oil and gas industry. Journal of Safety Research 59, 33-41. http://dx.doi.org/10.1016/j.jsr.2016.10.006.

Le Coze, J.C. (2015). Reflecting on Jens Rasmussen's legacy. A strong program for a hard problem. Safety Science 71, Part B, 123-141. http://dx.doi.org/10.1016/j.ssci.2014.03.015.

Liu, X., Huang, G., Huang, H., Wang, S., Xiao, Y., Chen, W. (2015). Safety climate, safety behavior, and worker injuries in the Chinese manufacturing industry. Safety Science 78, 173-178. http://dx.doi.org/10.1016/j.ssci.2015.04.023.

Lu, C.-S., Tsai, C.-L. (2010). The effect of safety climate on seafarers' safety behaviors in container shipping. Accident Analysis & Prevention 42, 1999-2006. http://dx.doi.org/10.1016/j.aap.2010.06.008.

McLain, D.L., Jarrell, K.A. (2007). The perceived compatibility of safety and production expectations in hazardous occupations. Journal of Safety Research 38 (3), 299-309. http://dx.doi.org/10.1016/j.jsr.2006.10.011.

Marchand, A., Simard, M., Carpentier-Roy, M.-C., Ouellet, F. (1998). From a unidimensional to a bidimensional concept and measurement of workers' safety behavior. Scandinavian Journal of Work, Environment & Health 24 (4), 293-299.

Mearns, K., Whitaker, S.M., Flin, R. (2001). Benchmarking safety climate in hazardous environments: A longitudinal, interorganizational approach. Risk Analysis 21 (4), 771–786. http://dx.doi.org/10.1111/0272-4332.214149.

Meyers, L.S., Gamst, G., Guarino, A.J. (2006). Applied multivariate research. Design and interpretation. Sage Publishing, Thousand Oaks.

Nahrgang, J. D., Morgeson, F.P., Hofman, D.A. (2011). Safety at work: A meta-analytic investigation of the link between job demands, job resources, burnout, engagement, and safety outcomes. Journal of Applied Psychology 96 (1), 71-94. http://dx.doi.org/10.1037/a0021484.

Neal, A., Griffin, M.A. (2004). Safety climate and safety at work, in: Frone, M.R., Barling, J. (Eds.), The psychology of workplace safety. American Psychological Association, Washington DC, pp. 15-34.

Netemeyer, R.G., Bearden, W.O., Sharma, S. (2003). Scaling procedures: Issues and applications. Sage Publishing, Thousand Oaks.

Nunnally, J.C. (1978). Psychometric theory. McGraw-Hill, New York.

Perrow, C. (1999). Normal accidents. Living with high-risk technologies. Princeton University Press, Princeton.

Podsakoff, P.M., MacKenzie, S.B., Lee, J.-Y., Podsakoff, N.P. (2003). Common method biases in behavioral research: a critical review of the literature and recommended remedies. Journal of Applied Psychology 88 (5), 879-903. http://dx.doi.org/10.1037/0021-9010.88.5.879.

PSA (2012a). Safety, Status & Signals 2011–2012. Petroleum Safety Authority Norway, Stavanger.

PSA (2012b). RNNP Risikonivå i norsk petroleumsvirksomhet 2011 [RNNP Risk level in the Norwegian Petroleum Industry 2011]. Petroleum Safety Authority Norway, Stavanger.

PSA (2014). RNNP Risikonivå i norsk petroleumsvirksomhet 2013 [RNNP Risk level in the Norwegian Petroleum Industry 2013]. Petroleum Safety Authority Norway, Stavanger.

PSA (2016). RNNP Risikonivå i norsk petroleumsvirksomhet 2015 [Risk level in the Norwegian Petroleum Industry 2015]. Petroleum Safety Authority Norway, Stavanger.

Rasmussen, J. (1983). Skills, rules, and knowledge; signals, signs, and symbols, and other distinctions in human performance models. IEEE Transactions on Systems, Man, and Cybernetics 13 (3), 257-266. http://dx.doi.org/10.1109/TSMC.1983.6313160.

Rasmussen, J. (1997). Risk management in a dynamic society: a modelling problem. Safety Science 27 (2–3), 183-213. http://dx.doi.org/10.1016/s0925-7535(97)00052-0.

Reason, J. (1997). Managing the risks of organizational accidents. Ashgate, Aldershot.

Reason, J. (2008). The human contribution: unsafe acts, accidents and heroic recoveries. Ashgate, Farnham.

Rosness, R., Grøtan, T.O., Guttormsen, G., Herrera, I.A., Steiro, T., Størseth, F., Wærø, I. (2010). Organisational accidents and resilient organisations: Six perpectives. Rev. 2. SINTEF, Trondheim.

Sinclair, R.R., Martin, J.E., Sears, L.E. (2010). Labor unions and safety climate: Perceived union safety values and retail employee safety outcomes. Accident Analysis & Prevention 42 (5), 1477-1487. http://dx.doi.org/10.1016/j.aap.2009.11.003.

Skjerve, A.B. (2008). The use of mindful safety practices at Norwegian petroleum installations. Safety Science 46 (6), 1002-1015. http://dx.doi.org/10.1016/j.ssci.2007.11.005.

Thompson, R.C., Hilton, T.F., Witt, L.A. (1998). Where the safety rubber meets the shop floor: A confirmatory model of management influence on workplace safety. Journal of Safety Research 29 (1), 15-24. http://dx.doi.org/10.1016/S0022-4375(97)00025-X.

Weick, K.E., Roberts, K.H. (1993). Collective mind in organizations: Heedful interrelating on flight decks. Administrative Science Quarterly 38 (3), 357-381.

Weick, K.E., Sutcliffe, K.M. (2006). Mindfulness and the quality of organizational attention. Organization Science 17(4), 514-524. http://dx.doi.org/10.1287/orsc.1060.0196.

Weick, K.E., Sutcliffe, K.M. (2007). Managing the unexpected. Resilient performance in an age of uncertainty (2nd ed.). John Wiley & Sons, San Francisco.

Weick, K.E., Sutcliffe, K.M., Obstfeld, D. (1999). Organizing for high reliability: Processes of collective mindfulness., in: Sutton, R.S., Staw B.M. (Eds.), Research in organizational behavior. Stanford Jai Press, Stanford, pp. 81-123.

Zohar, D. (2003). Safety climate: Conceptual and measurement issues, in: Tetrick, J. C. Q. L. E. (Eds.), Handbook of occupational health psychology. American Psychological Association, Washington, DC, pp. 123-142.

Zohar, D. (2010). Thirty years of safety climate research: Reflections and future directions. Accident Analysis & Prevention 42 (5), 1517-1522. http://dx.doi.org/10.1016/j.aap.2009.12.019.