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Article — Published Version

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Zeitschrift für Arbeitswissenschaft

Provided in Cooperation with:

Springer Nature

Suggested Citation: Rüpke, Irene; Athanassiou, Georgios (2024) : Contributing factors of fatigue on seagoing vessels, Zeitschrift für Arbeitswissenschaft, ISSN 2366-4681, Springer, Berlin, Heidelberg, Vol. 78, Iss. 4, pp. 469-491,
<https://doi.org/10.1007/s41449-024-00451-4>

This Version is available at:

<https://hdl.handle.net/10419/323698>

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Contributing factors of fatigue on seagoing vessels

A systematic literature review

Irene Rüpke¹ · Georgios Athanassiou¹

Accepted: 14 October 2024 / Published online: 15 November 2024
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Abstract

Seafarer fatigue as a risk factor in ship operations has gained attention in the maritime industry and research. The aim of this review is therefore to analyse the current state of knowledge based on literature from 2008 to 2023 and, in particular, to identify relevant influencing factors. The material analysed shows that fatigue and fatigue-like conditions occur in seafarers across ship and task categories. It is not only the individual characteristics of each seafarer that have an influence, but also the special features of the ship as a workplace, such as rough seas, long absences from the family and social interaction in a confined space. Long daily working hours together with the shift organisation cause short and often poor sleep. Activities and corresponding workloads are often unevenly distributed over the working hours of a small crew. Existing regulations and processes need to be improved, particularly with regard to working hours and crew sizes.

Practical Relevance

Maritime transport plays a key and growing role in the global economy. Safety and efficiency are therefore essential here in order to prevent damage to people, the environment and capital. Ship sizes and transport capacities are increasing, but crews are not getting any bigger. Better knowledge of the risk factors enables everyone involved, from the crew to the shipping company to legislators, to work more safely under the special conditions in international shipping.

Keywords Seafarer · Shipping · Fatigue · Fatigue-like states · Safety

Einflussfaktoren bei Fatigue auf Seeschiffen

Eine systematische Literaturübersicht

Zusammenfassung

Fatigue von Seeleuten als Risikofaktor im Schiffsbetrieb hat an Aufmerksamkeit in der maritimen Branche und Forschung gewonnen. Ziel dieses Reviews ist es daher, den entsprechenden Wissensstand anhand von Literatur aus den Jahren 2008 bis 2023 zu untersuchen und insbesondere relevante Einflussfaktoren zu identifizieren. Das untersuchte Material zeigt dabei, dass Fatigue und Fatigue-ähnliche Zustände bei Seeleuten über die Schiffs- und Aufgabentypen hinweg auftreten. Einfluss haben nicht nur individuelle Merkmale der einzelnen Seeleute, sondern auch die Besonderheiten des Schiffs als Arbeitsplatz wie etwa Seegang, lange Abwesenheit von der Familie und die soziale Interaktion auf engem Raum. Hohe tägliche Arbeitszeiten zusammen mit der Schichtorganisation sorgen für einen kurzen und oft schlechten Schlaf. Tätigkeiten und entsprechende Belastungen sind oft ungleich über die Arbeitszeit einer kleinen Besatzung verteilt. Gerade mit Bezug auf Arbeitszeit und Besatzungsgrößen müssen bestehende Vorschriften und Prozesse nachgebessert werden.

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Praktische Relevanz

Seetransport spielt eine tragende und weiter wachsende Rolle in der Weltwirtschaft. Sicherheit und Effizienz sind hier also unabdingbar, um Schäden für Mensch, Umwelt und Kapital zu vermeiden. Die Schiffgrößen und Transportkapazitäten steigen, doch die Besatzungen werden nicht größer. Eine bessere Kenntnis der Risikofaktoren ermöglicht es allen Beteiligten, von der Crew über die Reederei bis hin zu Gesetzgebern, die Arbeit unter den speziellen Bedingungen in der internationalen Seefahrt sicherer zu gestalten.

Schlüsselwörter Seeleute · Schifffahrt · Fatigue · Fatigue-ähnliche Zustände · Sicherheit

1 Introduction

Shipping plays a major role in global supply chain as almost 90% of global goods are transported by sea (Project Horizon 2012). In Germany alone over 279 million tons of cargo were handled in 2022, and 13.9 million TEU¹. At the same time, vessels are becoming larger while the crew size is reducing due to increasing automated solutions. With the increase in density of in demands and respective port calls, the question of the effects on the maritime workforce is a critical one, as crews are confronted with respectively different degrees of workload from extreme underload (e.g. during ocean crossing) up to extreme overload (e.g. continuous port calls in feeder or coastal shipping). Furthermore, working conditions on a merchant vessel pose additional social and physical demands due to the nature of their work.

Although currently numerous definitions of fatigue exist, the main constituent of these definitions agree upon the fact that fatigue is a state caused by some kind of physical and/or mental exertion (Phillips 2015). A general definition provided by Phillips et al. (2017, p. 743) describes fatigue: “as the body-mind response to sleep loss or prolonged physical or mental exertion”. Moreover, definitions may include different delineations of concomitant aspects to fatigue, such as the subjective experience of tiredness and sleepiness, fatigue as a physiological condition as well as an indicator for performance decrements (Phillips 2015). Each of these facets justifies and advocates the use of respective means for the holistic assessment of this complex phenomenon (Phillips 2015). The multi-faceted character of fatigue on the other hand calls for a specific and more differentiated definition of the construct that can allow for a better understanding and monitoring as well as a targeted management of fatigue through personal and systemic (i.e. ergonomics) measures (cf. ISO EN DIN 10075-1; ISO EN DIN 10075-2).

In the transportation sector as well as in shipping in particular fatigue has been repeatedly stated as a major chal-

lenge as well as a potential risk for the safety (Phillips 2016). One example of the dire consequences of the alleged onboard fatigue was the recent collision between the merchant vessels VERITY and POLESIE in the North Sea in October 2023 that left 5 seafarers missing or dead². Fatigue is not exactly the “new kid in the block” in the shipping industry. It is a critical concern for seafarers when discussing their working conditions as it is considered to be one of the contributing factors to maritime accidents, incidents and near-misses (Phillips 2016).

The International Maritime Organization (IMO) has issued several documents that emphasize the critical role of seafarers’ fatigue for the safety of shipping and provided guidelines for seafarers and companies for its effective management (IMO 2019). The guidelines are based on the following definition:

“A state of physical and/or mental impairment resulting from factors such as inadequate sleep, extended wakefulness, work/rest requirements out of sync with circadian rhythms and physical, mental or emotional exertion that can impair alertness and the ability to safely operate a ship or perform safety-related duties.” (IMO 2019, p. 1).

Furthermore, the notion of mental impairment in the definition, along with the aspect of physical demands, indicates the shift in the nature of maritime work from active control to system monitoring as well as the additional cognitive demands on information processing that are concomitant with the increased introduction of technology and automated aids in shipping (Lützhöft et al. 2011).

However, as implied by the above provided IMO definition, fatigue is often not defined in a precise, differentiable manner and can include several different fatigue-like impairment states, such as monotony, reduced vigilance, mental satiation and stress reaction as a result of a disturbance in the equilibrium between task- and situation-related demands and available resources (ISO EN DIN 10075-1 2018, Bakker and Demerouti 2017; Bakker et al. 2023).

¹ Statistisches Bundesamt (2023). Seeverkehr 2022: Güterumschlag 3.2% geringer als im Vorjahr. url: https://www.destatis.de/DE/Presse/Pressemitteilungen/2023/03/PD23_092_463.html (visited on 09/11/2023).

² As of this time (06.2024) the accident analysis by the Federal Bureau of Maritime Casualty Investigation is ongoing, however according to first assumptions fatigue may have contributed to the event.

The international standard for ergonomic principles relating to mental workload provides a more precise differentiation between the state of fatigue and fatigue-like conditions. Mental fatigue is thereby defined as:

“[the] temporary impairment of mental and physical functional efficiency, depending on the intensity, duration, and temporal pattern of the preceding mental strain” (ISO EN DIN 10075-1 2018, p. 8).

Consequently, the state of fatigue includes both a physical as well as a mental component regardless of the nature of the preceding strain (i.e. physical or mental) as physiological and mental fatigue possibly have a common physiological basis (Hancock et al. 2012; Phillips 2015). Although fatigue and the states of monotony, reduced vigilance and mental satiation are considered to be rather closely interrelated with respect to the subjective experience of fatigue as well as to respective detrimental effects on performance, fatigue is distinguished from the other states by the fact that compensation is only possible through means of recovery (i.e. breaks and sleep) and not by changes in activity.

The main focus of the study lays on fatigue as defined by the ISO EN DIN 10075-1 standard. However, studies in the maritime domain often rely on the above outlined and less differentiating definition of fatigue by the IMO for the description of the construct under investigation. This may be understandable due to the comprehensibility and practical relevance of the definition to the maritime community of both research and practice as well as due to a focus on strain and its potential effects on the performance and well-being of seafarers, and to maritime safety. However, this does not always allow for a clear differentiation between fatigue and fatigue-like states as object of analysis in the literature under review. Thus, in order to enable a comprehensive overview on the subject, the review will also consider and report empirical research that includes fatigue-like states when this has been deemed useful for the aim of the publication.

Therefore purpose of this paper is to provide an overview of methods of assessment and, most prominently, the major contributing factors for fatigue in shipping operations and more specifically in the context of work on seagoing vessels.

The respective research questions of the study consist in the following:

- Which methods have been utilized for the assessment of fatigue in seafarers.
- Which are the contributing factors of fatigue in the context of work on seagoing vessels.

2 Methods

The study was conducted as a systematic literature review. In order to ensure replicability and traceability of the process and the results, the Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) procedure was utilized for structuring and the documentation of the review (Liberati et al. 2009; Page et al. 2021). PRISMA consists of a checklist including all relevant steps for a literature review, from the selection process to comparison, bias and discussion. This strategy was utilized to ensure a structured approach while still considering interrelationships of the topic.

The first step was to decide on the keywords for the retrieval of relevant literature in data bases. The material was mainly reviewed by the first author (a licensed and active maritime deck officer), whose professional experience was helpful in the thematic delimitation of different maritime occupational fields. On the other hand, this was also helpful in categorizing the results with reference to the conditions of everyday work in shipping as a framework. The second author representing academia provided expertise in engineering psychology and maritime human factors and a respective critical conceptual and methodological guidance during the phases of the selection of search terms, of the review process as well as during the final categorization of the findings and the corresponding conclusions of the study. In this way, the present review combines both the perspective of occupational maritime practice and of human factors and ergonomics discipline.

Table 1 provides an overview of the keywords used for the study. The first trial with ‘fatigue AND seafarer’ gained very low numbers of relevant results. Therefore, the words ‘ship’ and ‘maritime’ were included in the search to also include articles whose titles only implicitly indicate that they refer to seafarers—e.g. to personnel on ships or maritime workers. Those were then combined with ‘fatigue/sleep’ as sleep was already mentioned several times together with fatigue in the literature during preliminary research (Baumler et al. 2021; Cui et al. 2022; Giot et al. 2023; Hansen and Holmen 2011; Hystad et al. 2013; Kerkamm et al. 2023; Lützhöft et al. 2010; Uğurlu 2016; Yancheshmeh et al. 2020). The asterisk (*) was used to include different word endings.

The table also shows that fatigue is a keyword that plays a major role not only in maritime research and that the search term was therefore added to some databases in order to reduce the number of hits from materials science (e.g. brittleness of steel) and medicine (e.g. fatigue after chemotherapy).

Only original research in peer reviewed articles has been taken into consideration for the systematic literature review. A pilot research in the library of Jade University of Applied

Table 1 Search keyword combinations used in each database (the asterisk * was used in the search term as a placeholder for different word endings)**Tab. 1** Verwendete Stichwortkombinationen und die jeweilige Datenbank (das Sternchen * wurde im Suchterm als Platzhalter für unterschiedliche Wortendungen verwendet)

Database	Keywords	Search Term	Results
Pubmed	Fatigue, seafarer	Fatigue AND seafarer*	265
	Fatigue, ship	Fatigue AND ship* NOT material NOT patient	485
	Fatigue, maritim	Fatigue AND maritim* NOT material NOT patient	321
	Sleep, seafarer	Sleep AND seafarer*	257
	Sleep, ship	Sleep AND ship NOT patient NOT child NOT mammal	992
	Sleep, maritim	Sleep AND maritim* NOT patient NOT mammal	253
Springer Link	Fatigue, seafarer	Fatigue AND seafarer*	127
	Fatigue, ship	Fatigue AND ship* NOT materia NOT engineering NOT patient NOT (child OR adolescent) NOT mammal	318
	Fatigue, maritim	Fatigue AND maritim* NOT engineering NOT patient	243
	Sleep, seafarer	Sleep AND seafarer*	149
	Sleep, ship	Sleep AND ship* NOT patient NOT (child OR adolescent) NOT animal NOT engineering NOT history	573
	Sleep, maritim	Sleep AND maritim* not patient NOT animal NOT (child OR adolescent)	331
Taylor Francis	Fatigue seafarer	Fatigue AND seafarer*	271
	Fatigue ship	Fatigue AND ship* NOT material NOT (structures OR engineering) NOT patient NOT (child OR adolescent)	296
	Fatigue, maritim	Fatigue AND maritim* NOT material NOT engineering	356
	Sleep, seafarer	Sleep AND seafarer*	593
	Sleep, ship	Sleep AND ship* NOT patient NOT (child OR adolescent) NOT history	1346
	Sleep, maritim	Sleep AND maritim* NOT history NOT animal	372
Scopus	Fatigue, seafarer	Fatigue AND seafarer*	145
	Fatigue, ship	Fatigue AND ship* NOT material	331
	Fatigue, maritim	Fatigue AND maritim*	398
	Sleep, seafarer	Sleep AND seafarer*	75
	Sleep, ship	Sleep AND ship*	327
	Sleep, maritim	Sleep AND maritim*	118
Web of Science	Fatigue, seafarer	Fatigue AND seafarer*	133
	Fatigue, ship	Fatigue AND ship* NOT material NOT (structures OR engineering)	298
	Fatigue, maritim	Fatigue AND maritim* NOT material NOT (structures OR engineering)	222
	Sleep, seafarer	Sleep AND seafarer*	75
	Sleep, ship	Sleep AND ship* NOT patient NOT (child OR adolescent)	290
	Sleep, maritim	Sleep AND maritim*	231
<i>SUM</i>			<i>10,191</i>

Sciences in Elsevier with the keywords ‘seafarer AND fatigue’ showed which databases with thematically relevant entries the author had access to. The databases then used accordingly for the research were the following: Pubmed, Springer Link, Taylor & Francis, Scopus and Web of Science.

Additional criteria for the selection of papers were based on the German Maritime Labour Act choosing people working on seagoing ships as part of the crew. Therefore during the screening of titles and later of abstracts, those papers focusing on pilots and offshore platform personnel were excluded. Studies were therefore included in which seafarers took part or whose topics were related to seafaring personnel. However, due to the very different framework

conditions on some types of ship, the term ‘seafarer’ was narrowed down even further here to ships used for merchant shipping. Studies focusing on fishing vessels were therefore excluded because voyages and economic demands of this industrial domain follow different patterns than merchant shipping and therefore have some special regulations, for example on resting hours. The same applies to members of the navy, who have duties very different from transport and therefore follow a different set of occupational rules for activities that differ from those in civilian seafaring.

The last general review on fatigue in seafarers was conducted in 2017, holding potential for new findings. It focused exclusively on quantitative work and therefore represented an insight rather than an overview of mar-

itime fatigue research (Dohrmann and Leppin 2017). The Maritime Labour Convention (MLC), the international regulation on on-board working conditions, was adopted in 2006 by the International Labour Organization ILO (ILO 2020). Therefore, only studies from 2007 or later are included: This excludes research projects that were possibly already underway when MLC was adopted and could have influenced the development and adoption process. In addition, this work focuses on material that relates to the current legal situation and not primarily to predecessor regulations of MLC. As no publications from 2007 fit the other search criteria, the oldest documents analysed are dated from 2008 onwards. That allowed for a comparison with selected older material in the discussion. This approach had the potential to show which insights are new and could yield new approaches for countermeasures, and which issues had been known already when MLC was prepared but still occur on board. This review was completed in January 2024. As different amounts of time may pass between the completion

of an article and its entry in the various databases, June 2023 was chosen as the end point of the analysis in order to present a comparable state of research. Studies that were not indexed until later are therefore not included in this review.

Figure 1 illustrates schematically the process of selection of sources during the systematic review, the further steps of which are explained below. The steps shown and the type of presentation in Fig. 1 followed the Prisma guidelines, where applicable: As will be explained in more detail in Chap. 3.1, the final selected literature contained a variety of methods and perspectives, so that the statistical comparison of the study results envisaged by Prisma was not reasonable here (Liberati et al. 2009; Page et al. 2021).

Table 2 provides an overview over the number of records excluded from the title screening process including the justification for the exclusion. Most of them lacked a maritime reference or the publication window between 2008 and June 2023 did not fit. Some of the remaining articles focused on fatigue in other professions and in different maritime areas and had to be excluded according to the seafarer definition in use (e.g. pilots, river navigators, marine soldiers, offshore crane operators, regatta sailors, divers, cruise passengers). Material on maritime but non-fatigue related topics (e.g. human factors on autonomous ships, piracy counteraction, ice-breaking techniques, search and rescue) was excluded as well as seafarers health research with other specialisations (e.g. digestion, seasickness, cancer, thermal strain) and studies on Covid-19 in shipping. The pandemic was a unique situation that may allow for valuable insights into seafarer health, but also may have induced atypical effects on fatigue by disturbing port procedures and crew change.

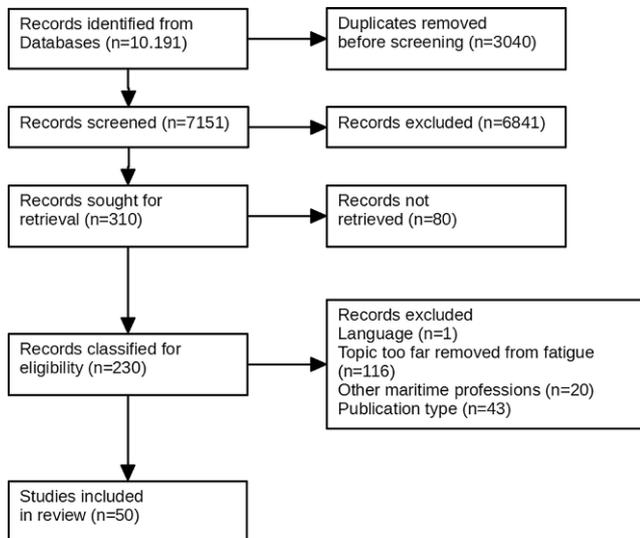


Fig. 1 Phases of the systematic literature review

Abb. 1 Ablauf der systematischen Literaturrecherche

Table 2 Number of records excluded in the title screening phase

Tab. 2 Anzahl der bei der Titelsichtung ausgeschlossenen Titel

Reason	Quantity
Duplicates	34
Distant topics, old works	6095
Maritime research not on fatigue	270
Fatigue in non-maritime sectors	169
Research on sea pilots	25
Research on fishing	43
Research on military seafarers	72
Other maritime medical topics	98
Covid pandemic focus	35
Remaining	310

Table 3 Exclusion criteria applied during the abstract screening process

Tab. 3 Angewendete Ausschlusskriterien bei Durchsicht der Zusammenfassungen

Reason	Details	Quantity
Publication	Document type	10
	Availability	24
Language	Italian	1
Topic	Other seafarer health	68
	Other human factors	35
	Legislation	7
	Research methods	1
	Maritime training	5
Other workers	Military	11
	Sailing yacht	1
	River barge	2
	Offshore support	5
Review	Pilot	1
	Literature review	9
Remaining		50

Therefore, publications with this specific focus were excluded.

After the removal of duplicates and the initial title screening, 310 records were sought for retrieval and screening of abstracts. Based on the predefined criteria of relevance, 50 out of these 310 records were included in the study after the screening of the abstracts (and part of the full-text in case of doubt).

Table 3 provides an overview of the records excluded in the phase of abstract screening. The document type (review articles, poster, opinions, research articles) and language (English) as well as the type of occupational sample and focus of intervention were checked and records were removed that did not correspond to the predefined criteria (i.e. original research in peer reviewed journal in English). Again, papers on other health concerns in seafarers (e.g. physical accidents), other human factors topics (e.g. motivation in seafarers), legislation (e.g. the International Maritime Organization), research strategies (e.g. measurement of physical activity on board) or improvement of maritime training (e.g. preparation of staff for multicultural cooperation on board). As with the previous search step, again literature on staff like maritime pilots and soldiers was excluded. 9 records consisted of literature reviews and were excluded to focus only on original research. Approximately 25% of the records that have been considered relevant for the study according to the criteria were not available for the study via the library service of Jade University of Applied Sciences.

In accordance with PRISMA guidelines, Table 4 lists all selected and reviewed studies and provides an overview of the selected methods, samples and focal points.

The table shows that the material comprised a variety of approaches, which made it necessary to structure the discussion. However, a detailed reading also revealed that, despite the diversity of the theses and results analysed, the variables considered to be contributory causes of fatigue were repeated across the material. This involved a total of nine topics that were repeatedly analysed, often in combination, across the literature: Working and resting hours, sleep quality and duration, shift rhythms, tasks, type of shipping operation, economic pressure, physical demands, social demands and individual characteristics. Each of the studies analysed discussed one or more of these topics. In line with these findings, the results were therefore grouped thematically in the following discussion.

3 Results

3.1 Methods utilized for assessing fatigue

The most frequently used physiological measurement is an armband activity monitor to track daily patterns of activity and rest (Cui et al. 2022; Lützhöft et al. 2010; Oldenburg and Jensen 2019a, b; Thomas et al. 2019). Performance was monitored using reaction and vigilance tests always in combination with psycho-physiological measurements or a subjective assessment (Li et al. 2022; Lützhöft et al. 2010; Mansyur et al. 2021; Özsever and Tavacıoğlu 2018; Ren et al. 2023; Thomas et al. 2019; Yancheshmeh et al. 2020). One study deployed a complex psychophysiological battery of methods was deployed (Kerkamm et al. 2023).

The most frequently deployed assessment method is self-reporting which includes not only survey and questionnaires but various formats. For instance, three studies focused on activity diaries (Lützhöft et al. 2010; Mansyur et al. 2021; Thomas et al. 2019). However, as their quality depends on seafarer's motivation, they were all combined with other strategies. Similarly, when questionnaires were deployed they were combined with other methods in order to moderate self-reporting bias. (Mansyur et al. 2021; Monteiro et al. 2020b, 2021; Oldenburg and Jensen 2019a, b; Pauksztat 2017b; Ren et al. 2023; Russo et al. 2022; Yancheshmeh et al. 2020). However, a large number of records solely relied on written responses (An et al. 2022; Andrei et al. 2020; Bal Beşikçi et al. 2016; Baumler et al. 2021; Dohrmann et al. 2019, 2020; Giot et al. 2023; Hansen and Holmen 2011; Hystad et al. 2013; Hystad and Eid 2016; Ishak et al. 2019; Kim and Jang 2018; Österman and Hult 2016; Rengamani et al. 2018; Salyga and Kušleikaitė 2012; Sarinas et al. 2022; Wadsworth et al. 2008). Mansyur et al. (2021) stand out being based on a Japanese questionnaire in order to take into account the cultural variety of seafarers.

Furthermore interviews are conducted to capture more complex facets of fatigue and its precedents (Akhtar and Utne 2014; Akyuz and Celik 2018; Russo et al. 2022) but also as means for investigating the interrelations with the regulatory framework through stakeholders (Shan and Lippel 2019; Shan and Neis 2020). Field studies can provide increased insight because the researcher will directly monitor processes during a voyage on board. However, due to the global movement of seagoing vessels, they represent a logistical challenge and require the participating researcher to remain objective despite the forced personal proximity on board. Still they are included in a few sources (Bhattacharya and Tang 2013; Kerkamm et al. 2023; Lützhöft et al. 2010; Oldenburg and Jensen 2019b).

Several projects investigated how the fatigue situation is reflected in documentation and legislation through document analysis such as resting protocols (Uğurlu 2016)

Table 4 Records reviewed
Tab. 4 Untersuchte Literatur

Identification	Aim	Methods	Sample	Determinants	Outcome
Akhtar (2014)	Human and organizational factors influencing grounding accidents	Regression analysis of accident reports to find determinants with highest impact	93 accident reports from 5 countries, having occurred 1997–2012	Manning, variable working hours, pilots involved, monotonous conditions	Manning and variable working conditions are main factors increasing fatigue probability
Akhtar and Utne (2015)	Fatigue factors influencing shipping accidents	Cognitive reliability and error analysis of accident reports to link error types and causes	33 accident reports from 2 countries, having occurred 1999–2011	Type of accident—collision or grounding	Communication and planning failures are most related to collisions, Groundings often happen in monotonous conditions. Overall missed observations are frequent and a safety climate allowing long working hours
Akhtar and Utne (2014)	Strategies to mitigate grounding accidents	Stakeholder interviews for an Analytical hierarchy process to compare possible measures	29 stakeholders (academics, consultants, insurers, authorities, shipping companies, seafarers)	Bridge resource management, fatigue prevention, safety climate, alcohol consumption restrictions, language barriers	Academics, authorities seafarers think fatigue measures are most important but also very expensive, consultants and shipping companies dont consider fatigue measures important
Akyuz and Celik (2018)	Impact of human factors on error probability in ballast water treatment	Probability calculation following risk weighting by experts	5 experts (4 management representatives, 1 master) from 4 companies	Fatigue, stress, complexity, time limitation, diligence and environmental factors	In Ballast water treatment fatigue is a less important risk factor. Time limits, complexity, stress have more impact on risks during the process
An et al. (2022)	Influence of vacation and service time length on Chinese seafarers	Questionnaire with simplified version of occupational stress scale from Japan	165 Chinese seafarers sailing internationally for various companies, flag states, ship types and ranks	Duration of contract and vacation	Long vacations lead to lower fatigue levels, long contracts increase fatigue. Officers are particularly affected, having the longest contracts and shortest vacation
Andrei et al. (2020)	Effect of work demands and resources on chronic fatigue in seafarers	Questionnaire on work assessment, monotony, decision-making autonomy, social support, fatigue	199 seafarers from one bulk shipping company, various ranks	Job autonomy, social support, monotony, recovery	Vigilance demands have negative impact on acute fatigue, job autonomy and support reduce acute fatigue under time pressure, chronic fatigue depends mostly on missing recovery
Balandong et al. (2019)	Development of a model for sleepiness detection	Bayesian network model development, sleepiness questionnaire and psychomotor vigilance tests for validation	24 participants	Time of day, wakefulness, circadian influence, sleep efficiency (time sleeping/time in bed)	Sleepiness prediction horizon of up to 12h was achieved based on subjective sleepiness assessments
Baumler, Bhatia and Kitada (2021)	Incidence and reasons for falsification of working time documentation	Seafarer interviews	20 seafarers from different nationalities, ranks, ship types	Workload, company support, legislation enforcement	Frequent adjustment of records shows current ISM procedures fail to successfully implementation of work/rest regulations
Bal Beşikçi, Tavacıoğlu and Arslan (2016)	Subjective assessment of fatigue levels on board	Interview and questionnaire on fatigue and mental health symptoms	31 seafarers on one tanker	Shift time of day	Overall seafarers are only slightly fatigued, workers on the night shift 0–4 were most affected

Table 4 (Continued)
Tab. 4 (Fortsetzung)

Identification	Aim	Methods	Sample	Determinants	Outcome
Bhattacharya and Tang (2013)	Impact of organizational measures on fatigue in the oil trade	Interviews ashore and during voyages on board	Management of two oil trading companies, two ships of each company (67 seafarers)	Safety standards, inspection frequency	Heightened standards and frequent inspections can increase safety but have the potential of high economic pressure and workload and therefore to fatigue
Cui et al. (2022)	Effect of engine noise on sleep parameters on board	Noise level measurement in accommodation, questionnaire on sleep parameters and quality	150 cadets from coastal research vessel	Noise level and frequency, operational condition sea/port	Noise levels correlate with sleep time, time in bed, sleep onset latency, noise levels are higher at sea
Dohrmann, Herttua and Leppin (2019)	Effect of family and organizational social support on fatigue in ferry employees	Questionnaire (Swedish Occupational Fatigue Inventory and Copenhagen Psychosocial Questionnaire)	193 board and terminal workers from two danish ferry companies (including 19 females)	Work-family conflict, supervisor support	Work-family conflict increased fatigue symptoms, supervisor support reduced physical fatigue in such cases
Dohrmann, Herttua and Leppin (2020)	Impact of different work stressors on ferry employees, possible moderating effects of sleep	Questionnaire (Swedish Occupational Fatigue Inventory and Copenhagen Psychosocial Questionnaire)	193 board and terminal workers from two danish ferry companies (including 19 females)	Physical stressors, perceived job demands, job control, sleep satisfaction	Physical stressors affected only a subjective loss of energy, job demands and missing control affected several aspects of fatigue, effects were reduced where sleep satisfaction was higher
Giot et al. (2023)	Incidence and variables related to sleepiness during navigational watch	Questionnaire on sleepiness and choice of countermeasures	183 officers (including 11 females) from various trades	Time spent on board, area of activity, watch system, monotony	Severe sleepiness is prevalent during watch, especially during monotonous watches and depending on sleep opportunities available on board; Caffeine was frequently consumed as a countermeasure
Hansen and Holmen (2011)	Influence of shift planning on sleep	Questionnaire on sleep disturbances and work safety	577 workers from Norwegian shipping company	Watch schedule 6 or 12h, noise, sleep quality at home	6-hours workers reported more sleep problems, especially with noise, but reported similar subjective working capacities to 12-hours workers; all rarely had problems sleeping at home
Hystad, Saus et al. (2013)	Safety climate psychosocial work environment, shift arrangement and their effects on fatigue	Questionnaire on sleep disturbances and work safety	402 crew from oil and gas industry	Safety climate, psychosocial work environment, shift organization	High psychosocial demands and low safety climate level lead to increased fatigue. Night shift workers were less affected by organizational and more by group safety climate
Hystad and Eid (2016)	Variables influencing sleep quality and fatigue on board	Questionnaire on Psychological Capital, Swedish Occupational Fatigue Inventory, Pittsburgh Sleep Quality Index	742 seafarers from offshore and Pax-RoRo vessels	Psychological capital, environmental stressors, seafaring experience, time at sea	Psychological capital significantly impacted sleep quality and fatigue, especially in connection with long on-board operations. Pax-RoRo workers were affected more strongly by fatigue than offshore staff
Che Ishak et al. (2019)	Human factors influencing marine casualty risks	Questionnaire on human factors and accident rate	60 workers from Malaysian oil and gas industry and maritime government agency	Fatigue, communication, technical knowledge	Strong correlation of fatigue and accident risk, lack of technical knowledge had a slightly higher impact and communication problems had a lower impact

Table 4 (Continued)
Tab. 4 (Fortsetzung)

Identification	Aim	Methods	Sample	Determinants	Outcome
Kerkamm et al. (2023)	Sleep architecture and related disorders in seafarers	Field study and feasibility trial of polysomnography, questionnaire including Epworth Sleepiness Scale	19 seafarers on container ship and bulk carrier	Sleep architecture, obstructive sleep apnoea, subjective sleepiness	Watchkeepers had a lower sleep quality than non-watchkeepers. Crew in general had a shorter sleep time, less deep sleep and a high sleepiness index during the day
Kim and Jang (2018)	Effects of organizational culture and fatigue on the quality of life	Questionnaire	280 seafarers from one company	Organizational culture and support, self-efficacy, fatigue, quality of work-life	Organizational culture and support as well as self-efficacy contributed significantly to perceived fatigue
Li et al. (2022)	Video-based bridge officer fatigue detection	EEG-based determination of fatigue levels in video-monitoring of deck officers, simulator trials	21 navigation students	Eyelid closure degree	Simulator trials found video-based fatigue monitoring feasible for performance monitoring and warning systems
Lützhöft, Dahlgren et al. (2010)	Impact of different watch systems on fatigue	Sleepiness diary, eye movement and reaction time measurement, wrist activity meter	30 watchkeepers on Swedish vessels in various trades (1 female)	Watch schedule 6-6 or 4-8	6-6 workers had higher sleepiness levels, shorter total sleep time and sleep was fragmented more often than for 4-8 workers
Mansyur et al. (2021)	Variables influencing fatigue in tugboat crews	Questionnaire including Pittsburgh Sleep Quality Index and Work-Family Conflict Scale, reaction time tests	127 crew members from several tug boats in Indonesia	Working time, sleep quality, work-family conflict, age, marital status, duration on board, length of seafaring experience, smoking status, coffee and alcohol consumption	Overall fatigue incidence is high, most important variables are working hours, sleep quality and work-family conflict. Individual determinants (age, marital status, experience, substances consumption) had no important impact
Monteiro, Li et al. (2020a)	Combination of sensor systems for objective fatigue detection on watch	ECG, EMG, body temperature sensor, EEG, eye tracking during simulator trials, Karolinska Sleepiness Scale questionnaire	11 subjects experienced in shiphandling	Fatigue and corresponding physiological reactions	The EEG has highest fatigue monitoring accuracy even without data from other sensor systems
Monteiro, Skourup and Zhang (2020b)	Optimizing fatigue monitoring systems based on EEG and ECG sensors	ECG, EEG during simulator trials, Karolinska Sleepiness Scale questionnaire	6 subjects with naval experience	Fatigue and corresponding physiological reactions	Successful test of a prognostic model with continuous transition from “no fatigue” to “fatigue”
Monteiro, Skourup and Zhang (2021)	Development of an algorithm for fatigue monitoring based on brain activity	EEG during simulator trials, Karolinska Sleepiness Scale questionnaire	12 maritime students	Brain activity patterns related to fatigue	EEG is found feasible for monitoring constant and changing levels of fatigue
Oldenburg and Jensen (2019c)	Impact of working time schedule on sleepiness	Pupillometry, armband activity monitoring, questionnaire including Epworth Sleepiness Scale and Morning-Evening Questionnaire	198 crew of all ranks on 18 container ships of different German companies	Work schedule—daywork and watchkeeping shifts	For all crew, sleep was found short and inefficient, watchkeepers were affected more strongly. Sleepiness was generally high, it increased during watches and is higher after a long time on board

Table 4 (Continued)
Tab. 4 (Fortsetzung)

Identification	Aim	Methods	Sample	Determinants	Outcome
Oldenburg and Jensen (2019b)	Effect of different phases of a voyage on stress and strain	Questionnaire, diary, armband activity monitoring, heart rate monitoring	323 crew of all ranks from 22 container ships of different German companies (236 participated in activity and heart rate measurements)	Voyage episodes: port stay, river passage, sea passage	Port stay was found to be most demanding with highest number of working hours and highest energy expenditure. Sea passages were rated the least straining
Orosa, Santos and Pérez (2011)	Effectiveness of fatigue prevention rules	Analysis of regulations and safety evidence on board (accident documentation, safety meeting protocols, documentation of preventive activities)	4 general cargo ships belonging to one company	Working hours, working environment	Bridge crew works the longest, but occupational accidents are more frequent on deck and in the engine. Working hours limits have to be adjusted to the conditions under which a task is completed
Österman and Hult (2016)	Impact of administrative tasks on fatigue, stress and exertion in short sea shipping	Questionnaire on work content and strain	651 Swedish seafarers working in short sea shipping	Position on board, ship type	Increasing administrative tasks increase exertion. But while under low administrative demands, catering crew and crew members from passenger vessels showed highest exertion values
Özsever and Tavacıoğlu (2018)	Work organization variables influencing performance on board	Interview on working schedules, electrodermal activity measurement, heart rate measurement, reaction time test	14 seafarers from 6 different container ships in different trades	Number of port visits, changes of circadian rhythm, working hours, watchkeeping duties	Changes in circadian rhythm are the most relevant determinant for drowsiness on board
Pauksztat (2017a)	Subjective perception of job demands and their effects in short sea liner shipping	Interviews with crew	54 crew members on 5 liner ships in different trades	Voyage episode (sea or port), demand dimensions (workload, cognitive effort, timing, planning ability, third party influences)	In relation to cargo operations, demands were perceived highest in port and where third party activities reduced the abilities to plan. High demands increased crew turnover and fatigue. A positive working climate reduced negative effects of demands and increased motivation
Pauksztat (2017b)	Impact of stressors and resources on fatigue in short-sea shipping	Consecutive interviews on board on work pressure, social interactions, voyage schedule and fatigue	Seven ships in Intra-European, Intra-Mediterranean and Intra-Caribbean traffic in various trades	Rank, Department, Shift organization, port calls, work pressure, social interaction on board	Fatigue was highest for deck department and higher for higher ranks and where port calls are frequent. Social support on board reduces fatigue as long as the number of port calls is not very high
Ren et al. (2023)	Development of a fatigue monitoring system to reduce reaction time for ship braking	EEG measurements during fatigue-inducing attention tests, fatigue assessment questionnaire	12 participants	Brain activity patterns related to fatigue	EEG is found to correlate subjective fatigue levels
Rengamani, Shameem and Poon-gavanam (2018)	Variables influencing fatigue in Indian crews	Questionnaire on work organization, tasks and fatigue	150 seafarers of Indian nationality from various ships	Sleep, stress, workload, ship environment, health	Most important determinants of fatigue were irregular and interrupted sleep, older age, time pressure (especially for deck crew), environment (heat, noise, vibration)

Table 4 (Continued)
Tab. 4 (Fortsetzung)

Identification	Aim	Methods	Sample	Determinants	Outcome
Riahi et al. (2013)	Modeling the effect of insufficient recuperation on performance	Bayesian network to model relations of determinants for crew performance	N/A	Time awake and cumulative sleep debt in combination with proficiency, fitness and skill	In comparison to accident reports the model is found to successfully evaluate the current level of performance an officer is capable of
Rodriguez, Campa Portela and Pardo (2012)	Applicability and impact of labour regulations on seafarers' safety	Discussion of IMO, ILO and EU regulations relevant for occupational safety in shipping	N/A	International occupational legislation	The current legal situation does not take sufficient account of the special challenges and dangers of seafaring
Russo et al. (2022)	Psychological variables influencing the probability of human error	Expert interviews, seafarer questionnaire, Bayesian Network modeling	61 seafarers with over 2 years of experience	Fatigue, anxiety, stress	Bayesian networks are feasible for assessing the psychological condition of seafarers. Fatigue was found highest on special purpose ships and deck officers. Young passenger deck officers were most vulnerable to error
Saharuddin et al. (2012)	Psychological variables influencing oil pollution legislation compliance	Analysis of training contents, questionnaires	522 Malaysian and Indian engine officers	Training duration, experience, attitude, fatigue	From the determinants, fatigue is most strongly related to oil pollution violations
Salyga and Kusleikaitė (2012)	Relation of psychoemotional strain, fatigue and health in seafarers	Questionnaires during health exams	1930 Lithuanian seafarers of various trades and ranks	Demographical variables, working schedule, environmental conditions, education, sleep quality	Long daily work, older age, noise and vibration and higher education increase strain in the subjects, especially when accumulated. Sleep disorders increase fatigue risk
Sarinas et al. (2022)	Variables influencing mental health in seafarers and countermeasures chosen by individuals	Questionnaire	100 Filipino seafarers from various trades and ranks	30 variables related to stress, fatigue, social conflicts on board and at home, work organization and climate, environment	Determinants ranked most highly by seafarers to impact mental health negatively: Stress, fatigue, separation from home, missing sleep, long stay on board. Most popular countermeasures are staying positive and interacting with crewmembers and family
Shan and Lippel (2019)	Crew change mutation as a health and safety risk in short-sea shipping	Analysis of applicable legislation, interviews	25 Canadian participants (crew, management, representatives, union representatives, charities, researchers)	Commuting time and distance	Long sign-on travel before the start of shiftwork increases the occupational accident risk. Related legislation has to be improved to increase this risk
Shan and Neis (2020)	Variables affecting safety in short-sea shipping	Analysis of applicable legislation, interviews	25 Canadian participants (crew, management, authorities, union representatives, charities, researchers)	Commuting time, vessel motion, environment, work organization	Long sign-on travel before challenging coastal navigation together with long shifts increases fatigue probability and accident risk. Recovery times are often insufficient
Thomas et al. (2019)	Fatigue occurrence in ferry personnel during peak holiday season	Wrist activity monitoring, reaction tests, Samn-Perelli Fatigue Checklist	12 officers on one RoRo ferry line	Sleep times and duration, sailing schedule	When the ship was sailing more frequently, participants took an increased use of sleep opportunities and kept alertness and performance high

Table 4 (Continued)
Tab. 4 (Fortsetzung)

Identification	Aim	Methods	Sample	Determinants	Outcome
Uğurlu et al. (2015)	Determining human causes of grounding accidents	Accident report analysis by Analytical Hierarchy Process	131 grounding accident reports from IMO, UK and Australia	Voyage management, team management, information application, individual behaviour	Most relevant grounding causes are lack of communication, position-fixing errors, lookout errors, interpretation errors, inefficient use of charts and equipment, fatigue
Uğurlu (2016)	Working and resting time compliance of oil tanker deck officers	Protocol of working times, tasks and crewmembers involved	20 masters and first officers in coastal oil tanker trade in Turkey	Time and duration of work	Deck officers' hours were in most cases found to be non-compliant with relevant IMO and ILO regulations. Accordingly, rest period regulations are not observed in most cases
Vinagre-Ríos et al. (2021)	Influence of circadian patterns and daylight on ship collisions	Analysis of collision reports	1163 collision accident reports from IMO	Watch schedule, outside light level	Accidents are more frequent and more serious during darkness. During the night they peaked at times of circadian low
Wadsworth et al. (2008)	Fatigue prevalence and variables related to fatigue	Questionnaire on fatigue, cognitive and general health	1855 seafarers from various trades and ranks (75 females)	Work stress, job demands, sleep quality, tour length, age, social support, physical hazards, smoking, port schedule, environment, working time, shift organization, social security	Work stress, job demands, low sleep quality, long tour length, young age, missing social support, physical hazards, smoking were related to chronic and acute fatigue, especially when several variables occur at a time. Port schedule switches, environmental demands, long working time, variable shifts, low social security relate to acute fatigue. Fatigue is related to lower cognitive and general health
Yancheshmeh et al. (2020)	Sleepiness and performance in oil tankers during cargo operations	Questionnaire (Karolinska Sleepiness Scale, Pittsburgh Sleep Quality Index), attention tests	70 deck officers of oil tankers in liner trade	Rank, time at sea, sleep quality	Highest performance and lowest sleepiness occurred during the second month on board. Second officers were most sleepy and performed lowest
Zong et al. (2021)	Development of a video-based fatigue detection system for the bridge	Video data processing for face and eye recognition	N/A	Duration and speed of eyelid closure	Video-based eyelid movement monitoring is feasible in lab conditions. Sea trials are still pending

and accident reports (Akhtar 2014; Akhtar and Utne 2015; Orosa et al. 2011; Vinagre-Ríos et al. 2021). Document analysis was utilized for the purpose of investigating the interdependencies between fatigue and the regulatory framework.

3.2 Contributing factors to seafarers' fatigue

3.2.1 Working conditions and resting patterns

The particular work conditions on board merchant vessels as well as and insufficient rest stood out as the most important precedents of fatigue (Dohrmann et al. 2020; Riahi et al. 2013; Wadsworth et al. 2008).

More specifically, temporal aspects of work such as work duration, break management and shift work have been outlined as important contributing factors to fatigue (Dohrmann et al. 2019, 2020). The international regulation for working time in shipping consists of the Maritime Labour Convention (MLC), first introduced in 2006 and last amended in 2010 by the IMO. According to MLC a normal workday last 8 h with one rest day per week. Maximum allowed work are 14 h per day or 72 h per week, minimum rest are 10 h per day or 77 h per week. The rest can be divided into maximum two periods per day, one of them at least 6 h long. Exceptions are possible for watchkeepers as well as short voyages where the crew has more possibilities for shore leave. In Germany, this is implemented in the Maritime Labour Act (Searbeitsgesetz), which contains similar regulations, including exemptions for short trips on two-watch vessels with a standard 12-hour-day, so the working day here can be longer than just eight hours.

However, the actual workday can be much longer (Baumler et al. 2021). With respect to the duration of work and its correspondence with fatigue, the findings in the literature vary depending on the sample and the specifics of shipping operations. Salyga & Kušleikaitė (2012) state 7 h based on a sample of 1930 Lithuanian seafarers, Mansyur et al. (2021) report a workday duration about 10.5 h for tug boat crews, and Wadsworth et al. (2008) based on a sample of 1855 seafarers report 12 h before the effects of fatigue are subjectively perceptible. Lützhöft et al. (2010) report based on a sample of 30 seafarers in two- or three-watch systems that crew members working two watches with usually at least 12 h per day are at a high risk for sleepiness. The overall results indicate that the recommended working time for preventing the occurrence of fatigue is less than the currently permitted 14 h.

However, regulations are often not thoroughly implemented and the actual working days on board sometimes even exceed the standard of 8 h and sometimes the maximum limit of 14 h per day. Long days are often the case as working overtime is assumed to be standard (Vinagre-

Ríos et al. 2021). Furthermore, maritime working regulations contain exemptions for emergency situations. In such cases the captain can override working hours limits. However, many activities on board are safety-related, so the definition of urgency gives a margin that is often exploited to complete tasks in addition to the usual overtimes. Uğurlu (2016) states that in the coastal oil trade especially first and second officers breach the limits during cargo operations in at least 80% of cases. Salyga and Kušleikaitė (2012) in their larger and more heterogeneous sample population give an average daily work of 9.1 to 9.4 h.

In addition, voyage phases (e.g. ocean crossing vs. frequent port calls) correspond with different demands with respect to the duration of actual working hours. Regulation violations seem to be more common during port call operations. Baumler et al. (2021) report that, when in port, 80% of seafarers work 12 to 15 h shifts. These numbers concur with other maritime research, where weekly figures of over 70 h or daily maxima of 15 h are reported (Oldenburg and Jensen 2019c). The figures differ depending on the ship and trade under investigation, because it depends on the ship and cargo type and the management how port calls are handled, for example if non-mandatory pilotage or additional staff for cargo operations is provided.

Seafarers' workload depends on the port scheduling and also on the cruising area, which affects traffic density and duration of river passage. The ship's command in particular is constantly challenged in channels and ports, without a chance for resting (Uğurlu et al. 2022). Economic demands and time pressure then often lead to breaches of the working time as tasks have to be completed during the scheduled resting time and sometimes they are even done during the navigational watch endangering shipping safety even more (Uğurlu et al. 2022; Yancheshmeh et al. 2021). The IMO Maritime Safety Committee (MSC) is also already aware of this in its 2014 report on fatigue and manning, focusing on two-watch vessels in particular (Maritime Safety Committee 2014, p. 2). However, the problem is also widespread on other types of ship as the financial reward for extra overtime may affect the motivation of liner shipping crew for extra overtime (Pauksztat 2017a). In addition to the economic pressure, bonuses make seafarers more willing to work overtime, even when not safe anymore (cf. Houtman et al. 2005). One additional explanation could lay in the fact that so much work is done on board is not least due to the often small crew sizes, which means that the necessary tasks can only be distributed among a few people.

A previously less researched aspect of working time is the sign-on and sign-off processes in short-sea shipping and their contribution to fatigue occurrence (Wadsworth et al. 2008). In two recent studies (Shan and Lippel 2019; Shan and Neis 2020) 25 crew members and stakeholders participating in Canadian short-sea shipping were interviewed

regarding the relationship of commuting and safety. Those crews often work far from their home and therefore have a long travel to work. The time spent underway to and from the vessel is frequently unpaid and there is no resting opportunity. Instead, board duties often begin immediately on arrival, especially in short-sea shipping where the port calls are short and frequent. So, fatigue can occur already at the beginning of the time on board. This observation is of particular interest in combination with the work of Österman and Hult (2016) on short-sea shipping. In this trade where crew change and port calls are frequent, seafarers often feel physically exhausted. A subjective feeling of reported (emotional) fatigue occurs more often after long voyages. So there seem to be different work patterns that affect the occurrence of the state of fatigue in different ways.

Finally, the duration of the contract and the respective time spent on board can influence the occurrence and prevalence of fatigue for seafarers (An et al. 2022). Currently only the deployment duration is limited, but there is no standard for recreation time. So, in cases of crew shortage, the vacation of the remaining staff will be shorter and the recovery might be incomplete (An et al. 2022). On short contracts of only days or weeks on RoRo (i.e. rolling goods such as vehicles) and offshore vessels, there was no strong correlation of fatigue and time on board in the work of Hystad and Eid (2016). While the authors suggest that the result should be interpreted with caution, due to potential underreporting and selection effects. However, it seems that on short contracts the schedule on board is more important than the contract duration (Giot et al. 2023).

3.2.2 Sleep quality and sleep duration

Andrei et al. (2020) describe in accordance the ISO EN DIN 10075-1 standard, how incomplete recovery on board negatively affects the development of fatigue and Dohrmann et al. (2020) as well as Vinagre-Ríos et al. (2021) and Yancheshmeh et al. (2020) mention rest and sleep as key influential factors of fatigue on board. Due to the ascribed criticality, resting times are regulated in parallel with working times.

Resting times on a ship follow a regime quite similar to the working time limits discussed in the previous section. Internationally, seafarers have to rest at least 10h every day or 77h in every seven-day period. The rest can be divided into two parts per day, but one must be at least 6h long. Like with working times, exceptions to these rules are possible for watchkeepers and short voyages (International Labour Conference 2020; IMO 2018). National law in Germany follows this pattern in general, including the minimum duration of six hours for one of the resting times and including an exemption when required by ship safety, but only with the respective compensation time. However, these rules can

be relaxed by collective agreement to include more exceptions for the case of operational necessity and rest time may be divided into three units. This is also the case for tugboat shipping for the sometimes quite short operations in port.

Two main aspects have emerged with respect to sleep as essential means for recovery: duration of sleep and sleep quality. Research shows how the resulting work and sleep schedules impact the crew. Seafarers usually work in shifts which affect their sleep pattern (Kerkamm et al. 2023). Poor sleep in turn affects the occurrence of fatigue during the voyage (Paukszta 2017a). Depending on the watch schedule, most seafarers have several sleep phases, usually one longer sleep and one shorter nap. Also, they have to balance non-watch activities (hygiene, meals, social and leisure activities) with sleep in the short period of time available. Uğurlu (2016) found that chief officers on oil tankers in the coastal trade often only rest between 50 and 60h per week (compared to the 77h required by legislation). Oldenburg and Jensen (2019a) in a study conducted on container ships in the Baltic sea (where port calls are frequent) reported that the average duration of sleep in the 24h before duty is only 5.6h, and even less for shift workers.

Kerkamm et al. (2023) used polysomnography (including EEG, ECG, eye tracking, muscle tone measurement, breath and snoring monitoring) on board to monitor seafarers' sleep. The sample was limited to 19 participants due to the complexity of equipment. They found indications that seafarers sleep only 5.4h per day. In addition, the participants went to bed increasingly late during their stay on board, which increases the problem over time. Thomas et al. (2019) deployed activity monitoring and reaction tests in their study. The sample (ferry officers) slept 7.3h per day in peak season. Interesting though, they slept more on days with more trips. Due to the rather short trips and short times on board in this sector, the experienced subjects had more chances to rest, and used them to prospectively tackle or compensate fatigue. So, seafarers are aware of the problem and may use recovery opportunities in trades whenever they see the opportunity thereof.

According to Giot et al. (2023) it also needs to be considered that not all off-duty times of the officers in their sample population are spent completely sleeping, but that relaxing enough to fall asleep after a busy watch takes time as well as other activities like eating, hygiene or sports.

Several authors state the importance of good sleep quality (Akhtar and Utne 2015; Dohrmann et al. 2020; Wadsworth et al. 2008). Notably, Mansyur et al. (2021) found out that 75% of tug boat crew members rate their sleep quality as poor and experience increased fatigue. Salyga and Kušleikaitė (2012) found a correlation of subjective sleep quality and subjective (i.e. reported) fatigue in a larger and more diverse sample. Oldenburg and Jensen (2019a) also highlight this point for container ship crews

with more recent data. Sleep quality as a problem is therefore evident in various studies across different ships and sailing areas. Watchkeepers spend less of their lie-down time actually sleeping, thus having a lower sleep efficiency, one of the symptoms of low sleep quality. It has to be said that the majority of the participants also consumed caffeine in the hours preceding the study which might affect sleep negatively.

Kerkamm et al. (2023) gauged the symptoms of poor sleep in seafarers with psychophysiological methods. They found that seafarers not only sleep shorter than average males, but also have a smaller proportion of rapid eye movement sleep (REM). This sleep phase is important for recovery and might affect daytime sleepiness. Also, a higher prevalence of sleep apnea was found, where short breathing arrests occur, which usually do not wake up the person but disturb the sleeping pattern and reduce the regenerative effect of sleep.

Finally, sleep quality of seafarers can be affected by the specific properties of the working environment. Cui et al. (2022) explored noise as the main source of disturbances affecting the sleep of 150 cadets. Over 50% of them stated to be annoyed by noise and woke up several times per night. The same researchers also measured sound levels on board and found them higher than recommended by the World Health Organization (WHO). This is legal on the one hand because recommendations are not mandatory. But it should still be considered critically, because current specifications are focused on prevention of hearing loss. In addition, while sleepiness has not been found to correlate with ship's motion, Oldenburg and Jensen (2019a), reported that seafarers still label ship movement (like pitching or rolling) as important sleep disturbing factors.

3.2.3 Shift work

As most seafarers work in the watch system, aspects known to be contributing to fatigue such as disturbances in the circadian rhythm also play a part. Hystad et al. (2013) questioned 402 crew members in the oil and gas transport on fatigue and showed that night shift workers reported increased mental fatigue and loss of energy. Furthermore, Dohrmann et al. (2019) in a study with seafarers that worked on ships which frequently had layovers in their home port (i.e. coastal ferries) and thus could often sleep at home, reported increased fatigue with those seafarers that frequently kept a night watch. Kerkamm et al. (2023) reported that, while day workers felt more subjective sleepiness, watchkeepers had the poorest sleep quality. But both groups showed high sleepiness during the day. One third of participants was thereby considered unfit for duty by the researchers. Oldenburg and Jensen (2019a) reported increased subjective sleepiness of container ship crews during

the watches from 0 to 4 and 4 to 8 in the morning, with over 17% of participants reaching a sleepiness level of six of seven on the Stanford Sleepiness Scale, meaning they were already fighting sleep and wished to lie down. Circadian patterns can also be found when looking at accidents at sea. The activities that occur during the day or night shift can certainly differ, but various studies have shown a conspicuous and strongly time-dependent accumulation of accidents. In the analysis of 33 accident reports conducted by Akhtar and Utne (2015) groundings occur most frequently between 22 in the evening and 7 in the morning.

Finally the issue of shift type has been found to contribute to the occurrence of fatigue on board merchant vessels. Akhtar and Utne (2015) report that shift and task scheduling that lead to irregular working times are often part of the chain of events leading to reduced performance and in the last consequence to a maritime accident. Salyga and Kušleikaitė (2012) report that an increase in irregular working times will correlate with fatigue. Pauksztat (2017b) conducted interviews in short-sea shipping where the short voyages often require changes in watch schedule, which prevented circadian adjustment to the working times, so fixed duty times were recommended as a consequence. Vinagre-Ríos et al. (2021) also recommend a fixed schedule after looking on the effect of circadian patterns on ship collisions.

3.2.4 Task demands

The occurrence and experience of fatigue of seafarers depends on the overall physical and mental demands of the job, and the specific demands of tasks and activities on board of merchant vessels (Dohrmann et al. 2019; Hystad et al. 2013; Wadsworth et al. 2008). Additionally, demands vary with respect to department, to socio-economic factors as well as to the social organization of work.

Fatigue affects staff members differently across the different departments (i.e. deck, engine room, catering). Österman and Hult (2016) report that catering staff in short-sea shipping was more affected by fatigue than the other two departments. Orosa et al. (2011) reported that catering staff on general cargo ships works the longest and with only small deviation between the days, so there were no longer chances for recovery in between. On the other hand, the findings of Pauksztat (2017b) on a study of seven ships in coastal trade appears to contradict the previous reports. Here galley staff reported the lowest pressure at work. A potential interpretation could be that while their tasks are time-consuming, galley staff interact less frequently with port or management personnel and are therefore less affected by external factors, such as schedule changes, inspections or economic pressure, and more by the social dynamics on board of the vessel.

Russo et al. (2022) conducted an accident risk assessment by interviewing 61 officers on the effects of fatigue, anxiety and stress. They found young deck officers hampered by fatigue and stress responses were the most prone to error. Navigation watch is described as their most demanding task, because successful completion of this duty is highly dependent on uncertain influences like environmental condition and traffic. On a similar manner Uğurlu et al. (2015), after analysing 131 grounding accidents, emphasize the importance of thorough navigation training and well-thought-out watchkeeping procedures, in addition to enforcement of limited working hours. Finally, regarding the engine department, only two studies addressed the issue of fatigue among engine staff. Saharuddin et al. (2012) questioned 522 engine officers and found a relation of fatigue and oil pollution incidents. Akyuz and Celik (2018) interviewed one master and four management representatives regarding errors in ballast water operation. They found fatigue to be less of a risk than time constraints or complexity of the equipment.

On board, phases of high and low workload often alternate, for example several port calls followed by a long sea passage. Monotonous tasks with long uneventful periods are more related to fatigue-like states that may manifest themselves as the experience of fatigue. However, as already stated, this type of tasks, which are rather typical in the maritime domain are often strongly related to the development of fatigue, even if they can be tackled through interventions in task design and task organization. In their investigation on accident reports, Akhtar and Utne (2015) found that collisions and groundings surprisingly often happen in calm sea conditions and good visibility especially at high levels of automation where not much activity is required from the watchkeeper in calm conditions. Monotony will increase sleepiness during the watch and impede reaction when active intervention is necessary. Navigational watch, especially at night when visibility is lower and traffic is less dense, often consists of monitoring phases interrupted by situations requiring quick and thorough action like a course alteration in case of an imminent collision. Andrei et al. (2020) indicate that vigilance demands also have a strong effect on chronic fatigue. They also note that more research on the effects of different tasks on seafarers' fatigue is required, as persistent monotony during task performance can also negatively affect sleep patterns. Effects of the growing use of automated equipment can also unwillingly contribute to fatigue due to increased monitoring demands with a simultaneous radical reduction of active system control something that has been highlighted in different contexts and especially in the context of highly automated driving tasks (Körber et al. 2015; Vogelpohl et al. 2019).

Not only does the department play a role in the development of fatigue, but one's rank in the on-board hierarchy also influences the occurrence of fatigue. Pauksztat (2017a) reports an interrelation between higher rank and fatigue in coastal trade. Similarly, Salyga and Kušleikaitė (2012) report a correlation of rank and fatigue in an extensive sample of Lithuanian seafarers. An et al. (2022) used an Asian occupational stress scale to allow for cultural characteristics in their research on Chinese vessels. And they found the same interrelation of higher rank and fatigue. Here a possible reason was brought out, too, because these officers had longer times on board and shorter holidays than other crew. The masters of the vessel seem to be particularly affected. In the research of Yancheshmeh et al. (2020), masters of oil tankers, while not participating in watches, still show low reaction test performance and low sleep quality.

Administrative tasks as a responsibility of senior officers may also contribute to the emergence and accumulation of fatigue. Österman and Hult (2016) report that exertion prevalence in short-sea shipping was significantly higher when at least 60% of work is of administrative nature. While administration is only one of many factors, the administrative workload did increase during the last decades. Procedures are often not designed efficiently, respective software lacks usability and paper duplicates are still requested.

On a final note, the type of contract and the rank also may play a distinguishing part in seafarers' fatigue. Different countries of origin (e.g. Philippines) also often mean diverging contractual conditions like duration, fixed and non-fixed contracts or a different probability of working as an officer or a crew member. It is therefore not surprising that the link of higher rank and more fatigue that is already established in several studies is not always true but partially due to implicit biases. Hystad et al. (2013) found that Filipino crew in Norwegian offshore shipping stated higher scores of fatigue than their Norwegian counterparts. The authors explained this finding in connection with the insight that employees under temporary contracts were found to be more affected by fatigue. Temporary employment via manning agencies is common practice for Asian crew on European vessels. This is probably less about a culturally induced increased susceptibility to fatigue and more about different working conditions depending on the country of origin. Here again is a need for more detailed research, because as Sarinas et al. (2022) criticize in their research on mental health in Filipino seafarers, currently the literature focuses on European or western seafarers.

3.2.5 Type of ships and shipping operations

Russo et al. (2022) found that passenger vessel crews experience higher fatigue than those on cargo vessels. This may

due to the higher responsibility when carrying passengers than goods. Bhattacharya and Tang (2013) conducted a field study on organizational safety measures in oil tankers. Due to the public interest in oil spills this trade has high safety standards and frequent inspections by the charterers. While this increases safety from a technical point of view, it also evokes additional work which in turn can lead to fatigue.

Orosa et al. (2011) show that work overtime on general cargo ships takes place more frequently while in the harbour and working accidents interestingly also occur more often in port than at sea. However, there are also other tasks to be performed here than at sea, such as securing cargo or manoeuvring, which may also increase the risk of accidents because of the respective increased demands, even with well-rested crews.

It was already mentioned that an increased number of manoeuvrers in coastal shipping is associated with increased fatigue levels (Pauksztat 2017b). In this trade, the port calls are often not only frequent but also of short duration. Prolonging them might give the opportunity to complete all duties before departure, instead of doing so during the watch after departure and thus reduce fatigue by allowing for rest before the next trip. The work of Oldenburg and Jensen (2019b) focused on feeder ships, small container ships mostly employed in distribution of goods in smaller regional ports. These spent around 60% of their time in port. During the port calls, additional tasks like deliveries or authority visits increase the number of stressors and lengthen the work day while noise and vibration disturb sleep and prevent recuperation. Another study of Oldenburg and Jensen (2019a) on sleepiness on container vessels also points out the additional demands of river passage and port, like crew change, pilotage or cargo operations. Vinagre-Ríos et al. (2021) argue that these additional duties are not only adding to the workload but also disturb the shift pattern and can therefore be related to fatigue-induced incidents.

3.2.6 Financial pressure

In port, in addition to loading and discharging activities, organizational framework conditions come into play that contribute to mental strain. During a port call the interests of various stakeholders must be brought together to ensure an efficient (i.e. effective and economical) transport. This often leads to conflicts for crew and master, who have to follow regulations on the one hand but are also expected to facilitate timely cargo transport in a competitive business. Pauksztat's work (2017b) on coastal ships in several world regions show that fatigue increases with perceived pressure at work. Efficiency pressure also is one of the main accident risk factors in the work of Akhtar (2014). The effect becomes particularly clear during a longer stay on

board (Andrei et al. 2020). In the study of Akhtar and Utne (2014) on accident risks, 29 maritime stakeholders (from shipping companies, authorities, insurances and research) were aware of the effect of efficiency pressure on fatigue and of fatigue on accidents. Still they assumed that the costs of fatigue prevention outweigh the benefits. Finally, reduced job autonomy and lack of support by the owner company contribute to higher levels of fatigue (Andrei et al. 2020; Kim and Jang 2018).

3.2.7 Physical demands of the working environment

Interestingly, there are not so many studies that address the impact of the physical characteristics of a vessel on fatigue. Therefore, there also is no regulation for a peculiarity of ships that is certainly known to sailors and passengers—the ship's own motion. However, despite suggestions from accident investigation authorities that link the cumulative occurrence of groundings in the winter season to worse sea states and therefore more frequent disturbances to sleep, Oldenburg and Jensen (2019a) did not find a correlation of movement and sleepiness.

Furthermore, the effects of continuous daytime exposure to noise and vibration on fatigue are neither described nor is their absence proposed. Seafarers state vibration and noise as main stressors in the survey of Oldenburg and Jensen (2019b) and engineers are particularly affected due to equipment running continuously day by day. However, the body of records reviewed in the study did not provide any insights regarding a direct interrelation between noise and fatigue.

3.2.8 Social demands of the working environment

Hystad et al. (2013) report that notably for night shift workers the team safety climate can indirectly influence the occurrence and tolerance fatigue in the oil and gas trade. As another example Giot et al. (2023) argues that a combination of ineffective regulations, a low priority on safety and a concern not to disturb social relationships can exacerbate states of fatigue and risk for safety as there is a reluctance to report poor fit for duty and request for relief in order not to burden colleagues. On the other hand, social support has been argued to function as a compensating mechanism against fatigue albeit only with limited effects. (Pauksztat 2017b; Wadsworth et al. 2008). In addition, more social support in the working environment seems to be associated with lower acute fatigue and better recovery afterwards, even in times of high job-related demands (Andrei et al. 2020).

Another factor that has been linked to fatigue is work-family conflicts. Seafarers often work far away from home for a long time while being hard to reach by phone or

through the web, in the meantime frequently providing an important income to the family. As a consequence responsibility is often high, but chances for communication are scarce. Mansyur et al. (2021) show that fatigue risk increases when work and family are more difficult to combine. They mention it together with long work hours and low sleep quality as the main influence factors. This is remarkable because the tugboat crews analysed tend to work on a weekly rather than monthly basis, meaning that they can see their families relatively frequently by seafaring standards. Dohrmann et al. (2019) also confirm the role of work-family conflict as a contributing fatigue factor for ferry crews.

3.2.9 Individual characteristics

Individual properties are a critical aspect for the degree of the experienced strain under similar conditions of exposure to stressors. Age has been found to be a contributing factor to the experience of fatigue for deck officers although the interrelationship is not always straight-forward (An et al. 2022). The findings indicate a counterintuitive relationship between age and fatigue, as younger officers are more likely to be susceptible to the effects than older and more experienced colleagues (Hystad et al. 2013; Kerkamm et al. 2023; Österman and Hult 2016; Russo et al. 2022; Wadsworth et al. 2008). A possible explanation is that older deck officers often have more favourable working hours in the shift system (masters often enough don't have to keep watch) and they use their experience as a compensation resource for an effective self-regulation during work (Kerkamm et al. 2023). In addition, Österman and Hult (2016) link this observation to the “healthy worker effect” suggesting that staff prone to exhaustion may leave the business earlier and seek alternative positions in the maritime transport industry (i.e. on shore offices and services).

Gender was strongly under-represented in the reviewed literature, something that is not surprising when considering the low percentage of female seafarers worldwide. Dohrmann et al. (2019) report that females experience higher fatigue-related physical discomfort than male participants. However, this finding should be interpreted with caution as a high number of shore employees was included in the sample.

Physical health was also surprisingly under-represented in the reviewed literature. Kerkamm et al. (2023) suggest that sleep apnea, which can strongly affect sleep quality and effective recovery, was more common with seafarers than their shore counterparts.

Similarly, mental health is also under-represented in the respective literature. This may be due to the detailed physical and mental checks seafarers undergo every two years (Dohrmann et al. 2019; Kim and Jang 2018). However,

the examination is limited to querying existing previous diagnoses and is dependent on honest self-disclosure. There could therefore be a need for further research in this area that has not yet been recognized. Dohrmann et al. (2020) state the importance of further research into individual resilience to better understand the interrelationship between fatigue and resilience.

Substance abuse has also been mentioned as a contributing factor to fatigue. Alcohol consumption have been referred to as exacerbating the effects of fatigue to performance (Akhtar 2014; Akhtar and Utne 2015). Although alcohol consumption is strictly regulated for workers on board of ships, consumption during free time may negatively affect the recovery process in terms of sleep quality impairments. Similarly, excessive nicotine consumption, something pretty common among seafarers, may also negatively affect sleep and thus increase the risk of fatigue (Wadsworth et al. 2008).

4 Discussion

The current study followed the PRISMA approach in order to derive the contributing factors of fatigue in shipping and more specifically in seafarers as well as the methods utilized for the assessment of fatigue in the recent body of scientific literature.

With respect to assessment methods, the reviewed studies employed mostly self-reporting instruments and less frequently interviews and psychophysiological methods for the purpose of fatigue assessment. The prevalence of self-reporting instruments is most probably due to the remote location and restricted availability of seafarers for a participation in empirical studies. Hence self-reporting methods are frequently deployed as they represent a parsimonious and efficient way for data collection under such circumstances. However, the validity of fatigue assessment via self-reports presupposes that subjects are knowledgeable and aware with respect to the complex nature of fatigue as a construct. When this is not the case, a large dissociation between subjective measures and ground truth as measured by objective psycho-physiological methods may emerge as demonstrated in the case of similarly complex constructs such as situation awareness (Endsley 2020).

In addition, the review findings indicate the multi-faceted spectrum of factors that contribute to fatigue in shipping on a systemic manner. The factors derived include the specific working conditions and resting patterns, task-related demands, shift work, type and specific properties of vessel and shipping operations, financial pressure, physical demands and social demands (including work-family conflicts) as well as the individual properties of seafarers.

The main contributing factors however consist in the special working conditions on board of merchant vessels and the effect these have on opportunities for adequate recovery including sleep duration and sleep quality. Duration and distribution of working hours typical for the industry seem to be major challenges for seafarers. Even if it is difficult to formulate generally applicable values for all those affected, the 14 h maximum working time permitted to avoid fatigue is inappropriate, especially considering the sleep deficit that builds up over the course of a contract. The literature review has shown that seafarers regularly sleep for only about five to six hours, often intermittently, over long periods of time which can be detrimental to performance as adults typically require seven to nine hours of daily sleep to avoid performance deficits (Härmä et al. 2008; Jepsen et al. 2015; Matsangas and Shattuck 2015; Paul et al. 2010; Strauch 2015).

In the case that work has to be done at night or irregularly, potential deficits may not be remedied by the usual crew sizes. The problem is exacerbated by the fact that sleep on board has been reported to be of a lower quality due to external conditions such as vibration and noise. The extent of this problem may not be clearly visible either within the shipping company or during official inspections because underreporting is often common practice in the shipping industry (Akhtar and Utne 2015; Andrei et al. 2020; Baumler et al. 2020).

The sleep deprivation as a precursor to fatigue seems to correspond with on board responsibilities that are concomitant with rank as well as the respective decision authority for operations. On the other hand, the high demands of frequent port calls and the associated time pressure due to the expectations of third parties can also increase the risk of fatigue among crew members. Thus, not solely the duration of the work, but also the (suboptimal) distribution and organisation of tasks may contribute to the occurrence of fatigue among vessel crews especially deck officers. However, one should also keep in mind that most studies focus on deck officers and watch keeping personnel. Hence, a selection bias may occur as other crew members may be under-represented as they may lack incentives, motivation or even access to studies of fatigue (Dohrmann and Leppin 2017).

Poor trust and poor support within the crew as well as between crew and management seem to have a large impact on the occurrence of fatigue and the respective performance detriments especially with respect to teamwork and system safety. Notwithstanding the extend of perceived trust and social support, the working environment on vessels (e.g. noise, vibrations) environment may also have negative effects that contribute to the occurrence of fatigue.

Individual aspects of fatigue are surprisingly understudied. Several studies state that age plays a role and that younger staff are more likely to be affected by fatigue.

Some studies also point to the importance of functioning interaction with the family. According to recent findings, the general state of health is also important. Health restrictions that lead to sleep apnea also affect the ability to recover through sleep.

Finally, contributing factors can also be considered on the sociotechnical systemic level, as both specific type of operations and vessels as well as the spill-over effects of financial pressure (in terms of time pressure and manning practices) in the utterly competitive environment of shipping seem to affect seafarers' fatigue. Even if regulations are adopted, the implementation is usually left in the hands of the shipping companies. Moreover, competition between these companies regularly results in very small crews, which are often officially approved due to the unclear legal situation, even though they obviously do not meet the applicable safety and working time requirements.

The studies under review show through their diversity of samples (e.g. in terms of crew nationality, shipping company or flag state) that this is a problem that occurs worldwide in international sea transport and cannot be allocated to a specific region or stakeholder. The need for sustainable industry-wide solutions for a systemic management of occupational hazards with the active involvement of affected parties (i.e. employers, employees, regulators) have been identified and respective programs have been introduced in other industrial sectors such as healthcare, manufacturing, construction and public administration (Hassard et al. 2012). Such identification and implementation of solutions in shipping would necessitate coordinated activities between employees (regardless of rank), employers (regardless of sector), charterers (regardless of cargo type) and regulatory bodies towards common problem definition, solution generation, decision-making as well as implementation and monitoring of the effectiveness of measures for fatigue management. However, such a process could be rather challenging due to both the specific employment conditions of the seafarers (temporary employment, crewing agencies) that may not allow them to represent their interests and thus prevent an active involvement in a truly participatory manner and due to the rather strong fragmentation of the labour market in the international shipping industry.

5 Limitation of study

This study has attempted to provide a comprehensive overview of contributing factors to fatigue in international maritime shipping. The main aim of this study was to gain an insight of the current state of research and to compare studies across different methods in order to make plausible statements about fatigue in seafarers across different study populations. In most cases, despite very different ap-

proaches, sample sizes and compositions, a similar picture of fatigue and the influencing variables emerged.

Nevertheless, there may be individual aspects that have not yet been considered comprehensively, especially very recent findings as records that have been published after June 2023 were not considered in the literature review. For example, possible concepts of measurement systems for fatigue are not discussed in the literature analysed until 2019. As of June 2023, the material cannot yet contribute much to the practical use and possible benefits of such systems in everyday on-board use. The material found consists primarily of cross-sectional studies. Studies from neighbouring occupational areas could therefore also serve as a basis for investigating the longer-term effects of the variables examined. The search strategy implied a preference for titles in English or indexed in English. There might be additional studies in other languages that also were not considered in this study.

The criteria selected for the search also naturally narrow down the results: Other maritime personnel such as naval personnel or offshore platform workers were excluded in order to limit the review to seafarers according to the definition mentioned at the beginning. However, such persons also work in shift systems and an isolated working environment. The insights gained here could therefore also be of interest for research on commercial ship crews. Interesting findings from neighbouring subject areas and from similar workplaces could provide further research approaches. In addition, the screening of records retrieved from the data bases was mostly performed by the first author of the study. Therefore misinterpretations and erroneous exclusions might have occurred. Finally, while efforts were made for maintaining a neutral perspective, the first author's experience as a watchkeeping officer in coastal trade might have shaped the view on work on board and the responsibility of the maritime transport industry as a whole.

6 Conclusion and outlook

Aside of the precedent factors that contribute to fatigue of seafarers, one has to consider the subsequent effects for performance, safety and well-being of this occupational group. In addition, research and practice will have to address fatigue with respective, well-designed and validated interventions for the purpose of prevention, monitoring and timely mitigation of fatigue effects. The current regulatory system monitoring fatigue on ocean going vessels is largely not evidence-based as it consists partly of non-binding guidelines. The implementation of many international regulations is the responsibility of the flag states. But their competition for tonnage as flags of convenience stands in the way of comprehensive implementation of even such regulations. Even

where regulations are adopted, the actual implementation of these standards is left in the hands of ship operating companies. In this situation, self-regulation through the interplay between employers and employees, which is common in other sectors, fails, as the employment conditions of the crews (temporary employment, crewing agencies) often do not allow them to clearly represent their interests. It was also already mentioned above that competition between shipping companies together with an unclear legal situation frequently results in a crew size that, as the literature under review shows, is not sufficient to fulfil all necessary duties on board while complying with international regulations on working and resting time.

With respect to further research, sleep duration and quality need to be further investigated with respect to potential effects of adverse situational and weather conditions (e.g. long nights, heavy seas). Long-term developments in the sleeping behaviour of ship crews should also be investigated in more detail. Initial studies on cadets indicate that the quality of sleep not only declines acutely on board, but also remains at a lower level in the long term, even when on holiday. The potential for relaxation on board is also linked to the organization of working hours. Studies from the military sector and initial findings from civilian shipping encourage to rethink the existing 4–8 shift system (ref needed). However, studies on different options for a distribution of working hours (e.g. an alternation of 3 and 5 h working time) are still pending. Here, sister ships with identical schedules could be used to compare the effects of shift systems.

The physical conditions of work on board (e.g. noise, vibration, ship motion) and their connection with fatigue, especially during physical activity, also need to be investigated in more detail for merchant shipping. Furthermore, additional research is necessary in order to investigate the effects (and feasible opportunities therefore) of exercise and nutrition patterns on fatigue.

Furthermore, future research should address possible modalities for real-time monitoring of fatigue correlates as well as early detection and notification options. Methods like video-based detection eye-tracking or portable EEG devices, although still unsuitable for practical implementation on board of merchant vessels may represent future viable solutions in this direction (Zong et al. 2021).

The development of fatigue is closely linked to the staffing levels on board. In particular, the provision of a lookout is regularly recommended to relieve the watchkeeper. The lack of a lookout is often cited as the cause in accident reports. However, the lookout as a safety measure must also be investigated on ships that have not been involved in accidents in order to be able to make statistically usable statements about its potential. Additionally, there is a need for the development and evaluation of evidence-

based guidelines for minimum crew sizes. For example, sister ships with the same schedule could be used to compare crew concepts and the corresponding occurrence of fatigue. Here it is important not to use the current manning levels as benchmarks because the current situation shows that existing regulations are not sufficient. The development and use of software solutions also offer potential here. On the one hand, it could simplify the planning of crew sizes by making it easier to compare the impact of parameters such as ship size and type, cargo, voyage plan and safety regulations on workload and fatigue for different crew compositions. Software could also help to not only document work/rest periods retrospectively, but also to plan ahead and identify phases with a high risk of fatigue and exchange corresponding information with the shipping company.

Overall, the literature used shows a focus on bridge personnel and officers in particular. Their areas of responsibility and the time distribution of tasks (e.g. in the harbour) differ from the requirements for catering and engine personnel and crews. It would appear worthwhile to focus more on these groups in the future in order to be able to recognize any deviating influencing factors or consequences of fatigue. Altogether, the sample composition must be well planned and documented in order to obtain comparable results.

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