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CLINICAL REVIEW

# Effects of fatigue on teams and their role in 24/7 operations

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SUMMARY

In 24/7 operations, fatigue from extended work hours and shift work is ubiquitous. Fatigue is a significant threat to performance, productivity, safety, and well-being, and strategies for managing fatigue are an important area of research. At the level of individuals, the effects of fatigue on performance are relatively well understood, and countermeasures are widely available. At the level of organizations, the effects of fatigue are also relatively well understood, and organizational approaches to fatigue risk management are increasingly well documented. However, in most organizational settings, individuals work in teams, and teams are the building blocks of the organizational enterprise. Yet, little is known about the effects of fatigue on team functioning. Here we discuss the effects of fatigue at the levels of individuals, teams, and organizations, and how the consequences of fatigue cross these levels to impact overall productivity and safety. Furthermore, we describe the pivotal role of teams in understanding the adverse organizational effects of fatigue in 24/7 operations and argue that teams may be leveraged to mitigate these effects. Systematic investigation of the effects of fatigue on teams is a promising avenue toward advances in fatigue risk management and provide some ideas for how this may be approached.



## Introduction

The cognitive/psychological and physiological effects of fatigue (defined here as reduced alertness [1]) on individuals are well documented [2] and, despite large inter-individual differences [3], can be relatively well managed with a wide selection of countermeasure approaches [4,5]. The impact of fatigue is also increasingly well understood at the level of organizations [6], and procedures and policies to manage fatigue are a developing research area [7]. In most organizations, individuals work in teams, which together form the organizational enterprise, and team work is central in many 24/7 environments. The field of human factors has examined the influence of fatigue on operations in the context of systems and behaviors that lead to adverse safety and performance outcomes [8]. However, there is a dearth of research investigating the effects of fatigue in team settings, particularly from a psychological and physiological perspective where the impact of 24/7 operations on individuals have been studied most extensively. This makes it difficult to establish countermeasures, procedures or policies that effectively manage the effects of fatigue on teams, or to leverage teams as a strategy to combat the adverse effects of fatigue on individuals and organizations.

Fatigue may be defined as the "inability to function at one's optimum level, because physical and mental exertion (of all waking activities, not only work) exceeds existing capacity" [9]. Inherent in 24/7 operations, which are common in healthcare, transportation, manufacturing, mining, military settings, and space exploration, fatigue is caused by extended time awake, long and/or intense work, waking hours that cross the biological night, and inadequate opportunities to recuperate through sleep [1]. While fatigue is a state of individuals, it stands to reason that it affects how individuals function within team, and thereby overall team functioning. In the Industrial-Organizational Psychology literature, teams are defined as "1) two or more individuals who 2) socially

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interact; 3) possess common goals; 4) are brought together to perform organizationally relevant tasks; 5) exhibit interdependencies with respect to workflow, goals, and outcomes; 6) have different roles and responsibilities; and 7) are together embedded in an encompassing organizational system, with boundaries and linkages to the broader system context, and task environment" [10]. This literature also provides us with frameworks through which the impact of fatigue on teams and team dynamics can be systematically studied.

The primary goals of this paper are to highlight the relevance of teams in fatigue-susceptible, 24/7 operations, to describe the knowledge gaps in how fatigue affects teams, and to highlight the opportunity presented by operationally relevant integration of fatigue and team research. We step through what is known, and unknown, about the effects of fatigue at the individual, team, and organizational levels. We then draw this knowledge together in order to provide structure and clarity to this interdisciplinary issue and outline avenues for further research.

## Fatigue at the level of the individual

### *Impact of fatigue on individual performance*

Individuals bring to the workplace a collection of knowledge, skills, and abilities on which they build to perform work tasks. These attributes are often assumed to constitute a stable foundation for individuals' contributions to the organizational mission. However, fatigue can have a dramatic impact on an individual's capacity to wield his/her knowledge, skills, and abilities effectively. In fact, fatigue appears to degrade task performance across a wide range of neurobehavioral functions [2], which can be grouped into three domains that are seen as key to the investigation of team performance (see next section): affect, cognition, and behavior.

Fatigue-related deficits in the domain of affect include reduced empathy, degraded ability to read facial expressions, emotional instability and amplified emotional responsiveness, impaired self-regulation, reduced positive affect and/or increased negative affect, reduced alertness, poor morale, and loss of motivation. Fatigue-related deficits in the domain of cognition include cognitive slowing, attentional failures, difficulties in memory recall, poor decision making, loss of situational awareness, reduced creativity, errors in task performance, and increased risk of accidents. Fatigue-related deficits in the domain of behavior include (physical) inactivity, perseveration (i.e., inflexible repetition of actions that are no longer responsive to the situation), poorly calibrated risk taking (overly risk seeking or overly risk averse), overreacting to provocations, distractibility, degraded quantity and quality of communication, and increased probability of falling asleep unintentionally. These and many additional effects have been extensively documented and discussed in the literature, and there are multiple reviews of the topic (e.g., [2,11–13]).

The effects of fatigue on neurobehavioral performance are relatively well understood, but people do not all suffer the exact same neurobehavioral consequences of fatigue. For one, there is considerable variability among persons in the magnitude of performance impairment due to fatigue [14]. This variability constitutes a trait [3,15], which does not appear to be predicted by other individual differences such as gender, intelligence, or personality, although genetic background may be modestly predictive [16]. Counterintuitively, whereas aging reduces tolerance to working in 24/7 operations overall [17], older age has been found to be moderately protective of performance impairment due to fatigue [18].

While it would seem reasonable to assume that individuals with high vulnerability to fatigue may self-select out of fatigue-inducing work conditions, this does not appear to be the case, even among highly select work forces such as jet fighter pilots [14]. Reasons for this may include domestic, educational, financial, social and/or lifestyle drivers of job and workplace selection, or the presence of punitive work policies that discourage workers from reporting fatigue. Another reason may be that there is considerable discrepancy between individuals' subjective estimates of fatigue or sleepiness and their objectively assessed level of neurobehavioral performance impairment [19]. Thus, workers may not be able to recognize their vulnerability and may think that they are functioning well despite being fatigued.

Another individual characteristic that determines the impact of fatigue, albeit indirectly, is morningness/eveningness or "chronotype" [20]. That is, some individuals prefer to get up early in the morning and go to bed early in the evening (i.e., morning-types), and some prefer to get up and go to bed later (i.e., evening-types) – a characteristic that is driven by individual differences in the timing of the biological clock [21]. As misalignment between sleep/wake and work schedules on the one hand, and the timing of the biological clock on the other hand, is a major driver of fatigue, it follows that different shift work schedules may have different fatiguing effects for morning-types as compared to evening-types [22]. Conversely, aligning work schedules with the timing of the biological clock improves sleep [23] and, by extension, may help to mitigate fatigue and associated performance deficits.

### *Task framework and operational context*

Importantly, the level of vulnerability to fatigue that each individual brings to the workplace depends on the task at hand [14]. A distinction can be made between tasks that predominantly 1) involve bottom-up processing of information generated by the task environment, as is the case in tasks that require continuous monitoring of systems and acutely detecting anomalies; versus 2) engage top-down attentional control to stay focused and facilitate decision making. Job tasks that depend substantially on bottom-up processing of inflowing information are common in operational settings with a high degree of automation. Laboratory analogs of these kinds of tasks have been studied extensively in the context of fatigue [24,25]. Chief among them is the psychomotor vigilance test (PVT), which has revealed that natural variability in cognitive processing speed is much increased under conditions of fatigue from sleep loss and/or circadian misalignment [26]. This performance "instability," which is commonly described as an increase in "lapses of attention," has been theorized to be caused by transient unresponsiveness of neuronal networks due to excessive prior use [27]. It has been hypothesized that the extent to which an individual is susceptible to this phenomenon depends on the capacity (or level of redundancy) in the neuronal networks underlying cognitive processing in the task at hand [28].

The transient unresponsiveness of neuronal networks associated with fatigue leads to brief disruptions in task performance, of which the moment-to-moment timing during a task is unpredictable [26]. Reason's "Swiss Cheese Model" of accident causation posits that errors and accidents happen when multiple potentiating factors come together in space and time [8]. Lapses of attention due to fatigue represent one such factor, but due to their unpredictable timing they rarely coincide with other factors, which implies a false sense of resilience and safety. Yet, because lapses of attention may occur at any moment, a fatigue-related accident can happen any time regardless of past performance and safety. This is particularly problematic in operational settings that rely heavily on reliable systems monitoring [1] and leads to rare but catastrophic accidents in safety-sensitive settings (e.g., the Chernobyl reactor meltdown and the Space Shuttle Challenger launch accident) [29].

Whereas performance instability is a potent aspect of performance impairment, it fails to account for various important other consequences of fatigue, such as poor decision making, loss of situational awareness, and perseveration. It has recently been shown that another, distinct aspect of performance impairment due to fatigue is involved, i.e., a profound deficit in cognitive flexibility [30]. This may be seen as an inability to flexibly shift between proactive attentional control, when there are clear expectations of what steps are needed to perform a task efficiently; and reactive attentional control, when appropriate actions are to be shaped by new information that needs to be evaluated first. Thus, fatigued individuals are able to maintain information in the focus of attention and anticipate actions that are likely to be effective to perform a task, but they are less able to prevent errors caused by competing information and, especially, adapt to suddenly changing circumstances [31]. These deficits lead to problems in situational decision making under time pressure, and may be especially detrimental during crisis intervention and other dynamic, rapidly evolving scenarios.

There may be yet another, potentially dissociable aspect of individual vulnerability to fatigue, involving deficits in self-regulation of affect and social interaction. Fatigue from sleep deprivation dampens emotional expressiveness [32], reduces emotional empathy [33] and humor appreciation [34], hampers charismatic leadership [35], and confounds socially interactive decisions [36]. Individual differences in these effects of fatigue have not been studied systematically, and would not be readily explainable in terms of lapses of attention or cognitive flexibility. Impaired self-regulation due to fatigue may have especially serious implications in team settings, and is therefore worthy of consideration despite this knowledge gap.

### *Temporal dynamics of fatigue effects*

A significant complication in considering fatigue in workplace settings is that the level of fatigue – and thus a worker's capacity to apply his/her knowledge, skills, and abilities effectively – changes dynamically over time. Principal drivers of this change are time of day and time awake, such that fatigue is greater during nighttime hours and after extended wakefulness (i.e., sleep deprivation), and less during daytime hours and after sleep [37]. An exception to this is a brief period immediately after awakening, which is characterized by a transient cognitive impairment known as “sleep inertia” that characterizes the brain's transition from sleep to waking function [38].

There is also a build-up of fatigue across consecutive days with sleep restriction [39], from which it may take multiple days without sleep restriction to recover [40]. Sleeping less than 6 h per night for 14 d leads to an accumulation of fatigue that is equivalent to a night without *any* sleep [39]. Interestingly, while objectively measured neurobehavioral performance deficits accumulate across days of sleep restriction, subjective ratings of fatigue and sleepiness do not show such a trend [39]. As a consequence, people may underestimate the impact of fatigue built up across consecutive days of sleep restriction, and may overestimate their readiness to perform in the workplace.

In addition to systematic temporal changes in fatigue related to time of day and time awake/asleep, there are numerous other drivers of fatigue that are predominantly transient in nature [41]. These include environmental conditions such as light exposure, ambient temperature, and background noise, and behavioral conditions such as consumption of caffeine or engagement in exercise (e.g., [1]). While a more detailed discussion of these factors is beyond the scope of this paper, it is important to keep in mind that fatigue is a dynamically changing property of an individual, which may change substantially even within the time span of a single work shift.

## Teams and fatigue in an operational context

### *Theoretical framework*

There are well-established models of team systems, which provide frameworks to consider the potential influences of fatigue. We anchor our discussion of teams in the comprehensive Input-Mediator-Outputs-Input (IMOI) model from the field of Industrial-Organizational Psychology, which considers the components and processes of team systems over time [42]. This model is complementary to human factors frameworks applied to operational fatigue [43], as it focuses greater attention to the psychological environment at the individual, team, and organizational levels, considering work experience in addition to performance and safety. For example, in the IMOI model, mediators such as team cohesion are explicitly considered as predictors of both behavioral well-being and performance. See Fig. 1 and the sections below for model definitions and discussion.

Drawing from general systems theory, the IMOI model is a framework of how teams operate and change over time. The model is conceptualized as a flow from inputs to mediators to outputs, which may then become inputs for subsequent team performance cycles. Inputs can be categorized by context: individual, team, or organization (Fig. 1). Individual-level inputs include such factors as the team members' respective personalities, knowledge, skills, and abilities, including underlying biological systems and trait-like vulnerability to fatigue. Team inputs include size, composition, roles, and leadership structure. Organizational inputs include the setting (e.g., corporate, military, athletic), operational context (e.g., office, virtual, field site), and environmental factors (weather, time of day, natural risks) within which the team works. These inputs contribute to, and interact with, multiple mediating phenomena that affect team task performance and social functioning outputs. Mediators, which are described in more detail below, are conceptualized as affective states, behavioral processes, and cognitive processes; see [10]. Team outputs, similar to team inputs, occur at the individual, team, and organizational levels, affecting individual performance and well-being, team performance and functioning,

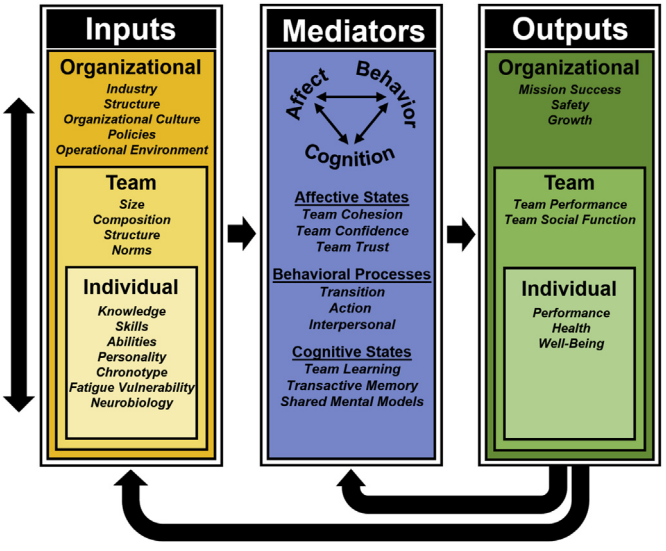


**Fig. 1.** The Input-Mediator-Output-Input (IMOI) model of team systems with identified fatigue-related inputs (adapted from [42,44]).

and mission success and safety, respectively. As a mission continues over time, a team repeats these IMOI cycles, with the outcome of each episode feeding back to shape the team's mediating processes and states while becoming a contextual input for the next team performance episode.

*Potential impacts of fatigue on teams*

It is assumed that the effects of fatigue on the team originate with an individual. Within the IMOI model, fatigue can be seen as an input variable that may influence mediators which contribute to the team's outputs. For simplicity in this discussion, fatigue will be considered in the context of established teams operating at a steady state of task performance capacity and social functioning. In so doing, it is assumed that the team possesses the necessary knowledge, skills, and abilities to be effective; is cohesive, confident, and trusting of each other; has established norms and shared understanding related to executing tasks and interacting with each other; and has performed effectively in previous task cycles. Later, how fatigue might affect teams at different points in their lifecycle will also be considered.

*Team inputs*

Within the IMOI framework, fatigue can impact the team at both the individual input and team input levels. At the individual input level, a team member's compromised ability to develop, retain, or apply the knowledge, skills, and abilities required for effective performance could adversely affect team processes and outputs. For example, fatigued individuals' reduced propensity to communicate contributes to errors in team-based operations [45].

At the team input level, the inclusion or introduction of a fatigued individual may change the team composition. If one or more team members experience a significant reduction in neurobehavioral capacity due to fatigue, then the team size is effectively reduced, which reduces the available pool of knowledge, skills, and abilities needed to complete the tasks as designed for the team as originally sized. A redistribution of effort and/or increased workload across the remaining team members may be less detrimental in relatively large and/or less interdependent teams, but could critically compromise performance in demanding, time-pressured, safety-critical, and interdependent tasks in small, high-performing teams, for example in emergency response to an onboard fire in a submarine or space vehicle. For less time-pressured tasks, the team may show resilience to critical failure from degraded performance of a fatigued team member by slowing down, but this may create delays. Chronic fatigue in one or more team members may reduce schedule flexibility over time, as the team continues to be functionally understaffed, potentially resulting in failure to complete some mission tasks and longer-term goals.

Fatigue may also have functional effects on team structure, specifically role assignments and leadership positions. If a team, especially a small, high-performing team, has clearly delineated roles and expertise with limited redundancy, then the diminished capacity or functional loss of a team member due to fatigue could be devastating. Effective leadership and structured roles support performance of team processes and team cohesion [46], and a fatigued leader may partially or totally abdicate the leadership position (e.g., [47]) as fatigue negatively affects self-regulation, motivation, communication, and other characteristics needed for effective leadership. Studies of fatigued leaders have revealed that they are more impatient, irritable, and hostile, with these negative attributes persisting over time [48]. These personal characteristics then impact the rest of the team, reducing trust, motivation, and ultimately performance. Notably, individuals' awareness of the untoward effects of their fatigue on others is limited [48]. A compromised leader who fully asserts authority under diminished capacity for judgment and decision-making without recognizing his/her impairment and without any countermeasures or safeguarding procedures in place is a risk factor for organizational errors and accidents.

*Team mediators (processes and states)*

Team mediators fall into three categories: affective states, cognitive states, and behavioral processes ([44]; Fig. 1). Each category includes multiple subcomponents (see below) [49]. The affective and cognitive mediators are considered “emergent states,” that is, they are inherently team/social phenomena that develop through dynamic interactions among the team members and tend to stabilize over time [10,42]. Behavioral processes within the team system are also inherently team/social-based, but involve overtly observable actions (e.g., conflict management) that can contribute to team performance outputs in their own right and also serve as objective indicators of emergent affective and cognitive states. The mediator phase in the IMOI model is where the negative effects of individuals' fatigue are expressed and ultimately shape team performance and functioning.

*Affective states*

In the team context, “affective states” is a broad term encompassing bonding to the team and its task; confidence in team members' knowledge, skills, and abilities; and emotional processes and reactions [10]. Teams in 24/7 operational contexts such as military, spaceflight, transportation, and mining often live and work together over extended periods, increasing the influence of affective factors since team members must often act as coworkers, roommates, friends, and social support [50]. Many studies have found that team cohesion, which can be broken down into task cohesion (i.e., working well together, shared goal commitment) and social cohesion (i.e., living well together, shared attachment and liking) [51,52], is positively related to team performance (e.g., [53,54]). Similarly, team confidence is composed of team efficacy (i.e., shared belief in capability to perform a task) and team potency (i.e., shared belief in a teams' general capability to achieve mission success; [44]). Finally, team trust and team psychological safety allow team members to be vulnerable, open, and challenge each other, and these factors are also positively related to team performance [55].

It is unknown exactly how fatigue may impact these emergent affective states of a team at any point in its lifecycle. However, it is not difficult to imagine their formation, maintenance, or repair may suffer when influenced by a fatigued team member's emotional instability, inattention, poor self-regulation, or outsized emotional responses. If fatigue exerts added pressure to an already stressed system, then it may cause a team to reach dysfunctional levels of reduced team cohesion more easily [56]. Notably, the cohesion and performance relationship strengthens over time [53,54]; thus, a fatigue disruption may cause a downward spiral as mediator and output interact over time.

The limited literature on team affect and fatigue has focused primarily on behavioral indicators of cohesion and trust, such as decreased team effectiveness over time as seen in fewer leadership messages and more puerile communication in one laboratory study of simulated US Navy watch teams restricted to 6.5 h of sleep for four days [57]. In studies using anonymous partners, participants were less likely to place trust in the anonymous partner [36] and more likely to engage in socially influenced deception [58] after total sleep deprivation. However, fatigue studies have not directly

assessed team affective states at the subjective level by using surveys explicitly asking whether an individual or team believes the team is cohesive, has confidence, or is trustworthy. Using observational ratings of behaviors, "big data" analyses of communications, physiological indicators, or monitoring physical movements and interactions, may all be used to provide convergent measures of these affective states in addition to subjective measures [59], but this has received very little attention in the literature examining team functioning under fatigue.

*Cognitive states*

Team cognitive states may also suffer from individuals' fatigue-related cognitive decrements. As operational teams perform tasks and may even live together, they must problem-solve in both the professional and social arenas. Shared understanding (i.e., a shared mental model) of the team's goals, processes, and norms, and shared situational awareness, support team performance [60]. Other team cognition that supports performance and team functioning (e.g., cohesion) includes transactive memory systems (i.e., knowing who on the team knows what and leveraging the collective team memory) and team learning (i.e., reflecting on past performance to adapt and improve; [44]). As fatigue may cause loss of situational awareness [31] and decreases the cognitive processing of information [61], team members' shared understanding may begin to disintegrate, while the collective memory of the team's expertise and lessons learned from past performance episodes may erode or become less accessible. We are not aware of any empirical research systematically examining these complex team cognitive states under conditions of fatigue.

*Behavioral processes*

Behavioral processes are influenced by team affective and cognitive states, each team members' individual knowledge, skills, and abilities, and fatigue. Fatigue may cause a team to lose efficiency and effectiveness in executing team behavioral processes due to individual impairments in attention, motivation, working memory, processing speed, risk taking, and/or cognitive flexibility. During a team task, teams progress through a series of behavioral transition and action processes, with interpersonal processes as an ever-present third dynamic [42]. Foundational team-oriented behaviors such as communication are woven throughout these processes. For example, a study of US Army teams during a 36-h artillery fire operation simulation found that after 24 h, teams stopped communication upon receipt of relevant info, and performance was decremented accordingly [62].

Behavioral transition processes include mission analysis formulation and planning, goal specification, and strategy formation, while behavioral action processes include monitoring progress toward goals, systems monitoring, team monitoring and backup/supporting behavior, and general coordination. For behavioral transition processes, fatigue may impair judgment and decision-making and cognitive flexibility, thereby negatively impacting the team as the members synthesize and prioritize information. In high-consequence, dynamic environments that change rapidly over time, impairments in re-planning and strategizing based on new information may have serious safety outcomes [63]. One study of professional football and basketball teams found that travel stressors (e.g., eastward travel, distance traveled, frequency of travel, back-to-back travel) resulted in more risk-taking and poor judgment and decision-making as evidenced by a higher number of team-level penalties [64]. This study also found a partial mediating effect of team concentration and an overall negative effect of travel stressors on team performance (i.e., difference in score, difference in performance during the game). However, the team may be able to overcome individual-level fatigue effects on behavioral processes. For example, in a laboratory study of team decision-making, errors and processing time increased at the individual level but these effects were attenuated by team membership [65].

Behavioral action processes follow behavioral transition processes, such that the team begins to implement identified plans and strategies to reach agreed-upon goals. Behavioral action processes require considerable attentional resources as team members monitor progress, systems, and each other. In a well-orchestrated team, members maintain situational awareness and a shared understanding, which allow them to efficiently and effectively coordinate actions in the proper sequence. Once fatigue disrupts this process, errors in coordination and backup behavior may occur. Poor decision-making and reduced situational awareness at the individual level is also particularly critical during behavioral action processes, as team members constantly make decisions regarding what to monitor, what and when to communicate to others, when to step in to provide backup, and how and when to execute interdependent actions. There is little research in this area. A US Air Force study of a 36-h air battle management task showed that teams sought more visual information when fatigued, but that overall performance did not decrease [66]. While little research has examined fatigue on team-level action processes, several studies have considered fatigued team communication, which is required for many coordinating actions. Generally, fatigued teams exhibit less communication [62,67].

For the behavioral interpersonal processes of conflict management, motivation and confidence building, and affect management, fatigue may prevent deployment of team-established strategies of managing relationships, as poor self-regulation and amplified emotional responses cause team members to simply ignore those strategies [68]. The well-documented fatigue effects on motivation, mood, empathy, morale, self-regulation, and other affective and interpersonal factors [2] strongly suggest that a fatigued team will experience an increase in conflict and a reduction in prosocial behaviors. For example, laboratory studies found sleep quantity to be negatively related to unethical behavior, while a field study of organizational employees found that sleep quantity and quality predicted unethical behavior [68]. Other studies found sleep quantity to predict helping and prosocial behaviors directed toward the organization but not toward individuals, while a student sample found that sleep quantity predicted prosocial behaviors directed at both individuals and organizations [69,70]. Reduced prosocial behaviors may also exacerbate fatigue. For example, residential support workers on night shifts reported less sleep when colleagues did not provide backup behavior in the form of assistance in completing tasks [71]. These few studies examining team behavioral processes and fatigue have not examined all potential effects on the process subtypes, and there has not been much replication to support strong conclusions.

*Team outputs (and the cyclical nature of teamwork)*

Team outputs are grouped into two categories: team performance and team functioning. Team performance may be measured by, depending on the setting, patient mortality rates, military targets hit, space monitoring equipment installed, etc. Team functioning may be gauged by team cohesion and team confidence metrics. These outcomes determine team output, and also affect the individual team members' performance, safety, and well-being. Often the metric of primary interest in operational environments is the ultimate team performance; that is, did the team complete the task and the mission, and did they do it safely? Fatigue may

influence operational outcomes directly (e.g., failure to detect a target resulting in a miss), but in a team setting, fatigue acting on the team processes also drives later team outcomes.

A team that is particularly reliant on each member performing a unique and critical role may suffer significantly if one or more members are unable to fully contribute. However, it is possible that the effects of fatigue on team tasks only impact individual processes (e.g., information gathering) without significant consequences to overall team processes (e.g., information sharing, coordination) or outputs (e.g., task completion) [72]. In other words, a team may be able to overcome the negative effects of fatigue on one or more members to accomplish task and mission objectives. In effect, each member of the team can serve as a potential layer of risk mitigation in Reason's "Swiss Cheese Model" of accident causation. Many team settings have developed informal processes of fatigue proofing to do exactly that [73].

Industry-based studies support the importance of teams for managing safety-critical performance [74] and team-level protection against threats from fatigued team members [75,76]. At the same time, fatigue may erode prosocial behaviors and the ability to be a "good team member" [77]. As such, if a team member is identified as fatigued, other team members may strategically redistribute tasks, add backups and checks, and prompt increases in communication. Training a team in how to perform these mitigation strategies, while also maintaining a cohesive environment in which members are able to expect and accept performance decrements and maintain trust in all team members, is challenging but may have long-lasting, positive consequences.

Indeed, team outputs evolve, flowing naturally into the next episode of team performance and creating a new set of inputs for the next IMOI cycle ([42]; Fig. 1). For example, team performance predicts team cohesion [54], and each task is also an opportunity for the team to practice or learn skills and processes, preparing them for the next application of those skills and processes. Each episode may also influence fatigue (e.g., through the time on task effect [1], or by impacting on subsequent sleep [78]), which may result in a team member or members beginning the next task more fatigued. For example, astronauts have reported worry related to tasks performed inadequately earlier in the day affecting sleep that night [56].

Over time, a team that experiences a pattern of poor performance will also experience a decrease in team cohesion, trust, and confidence, which leads to another decrease in performance and an increased likelihood of accidents, and so on — until ultimately, the overall mission is at risk of failure. In the case of a new or forming team, disruption due to fatigue during an early IMOI episode could prevent the team from ever becoming a well-functioning, high-performing unit. To develop strategies to avoid or reverse such a fatigue-induced downward spiral and mitigate the risks of fatigue on performance and safety in team settings, understanding the nuances of how fatigue influences the components and processes of team systems is critical.

## Organizational context

### *Operational framework for managing fatigue*

As represented in the IMOI framework (Fig. 1), the effects of an individual who is fatigued can ripple through an operation. For example, in the commercial aviation environment, an error from a single fatigued air traffic controller can result in process changes for others in the air traffic controller's team. In turn, this can result in delays in landings and take-offs and disruption of the scheduling and flow of an entire airport. This can then have follow-on effects for plane scheduling at destination airports, influencing the flow of the larger airline system. In any tightly connected organizational system, ripple effects from a single fatigued individual can impact on organizational integrity through changes in productivity, safety, staffing, turnover, recruitment, retention, quality control, and accountability [79,80].

The traditional approach to fatigue management at the organizational level has focused on hours-of-service (HOS) regulations prescribing limits on shift duration, mandatory breaks, and time off [6]. Such regulations seek to structure working time arrangements to prevent excessive time awake and time on task, and to allow sufficient sleep opportunity. However, HOS regulatory approaches have been criticized for failing to sufficiently consider factors such as time of day [6,80,81]. Importantly, HOS regulations prescribe individual behavior, and only consider their behavior at work. Unlike other workplace hazards (e.g., toxic exposure), not all factors that influence fatigue occur within the work environment.

Managing fatigue is therefore increasingly seen as a shared responsibility of both the individual worker and the employer [7,82]. In many parts of the world, Occupational Safety and Health regulations identify this shared duty to manage fatigue by employer and employee [80,82]. Typically, responsibility for fatigue management centers on the regulator, the operator, and the individual worker [82]. The employee's duty to be fit for work is more complicated for fatigue than it is for other sources of impairment (e.g., alcohol or other drugs), as it is often not possible to completely remove fatigue from a workplace (especially in 24/7 operations). Moreover, fatigue is a dynamically changing state (often increasing across the duration of a work shift), and it cannot be easily assessed objectively.

Given these challenges, current best practice in fatigue management in large-scale industrial settings involves the development of a fatigue risk management system (FRMS) [6]. Based on the "Swiss Cheese Model" of accident causation, the FRMS framework acknowledges that no single means to prevent errors or incidents is perfect, and there must be multiple, overlapping, and redundant levels of protection [7,82]. Teams are a natural part of this framework, as team members monitor each other, coordinate schedules and work flow, and support other team members to maintain performance effectiveness and enhance error avoidance. Team members may also need to be understanding toward teammates reducing workload due to fatigue. While it is widely recognized that an effective and mature workplace culture is essential in this context [82], the role of teams and the implications for team behavioral processes have not been given any systematic consideration.

### *Teams and fatigue management*

What is currently missing from the FRMS framework is explicit reference to the way in which team dynamics inform fatigue management and vice versa. There is a need for a conceptual model for the incorporation of teams in FRMS. Current thinking by Le Coze [83] and others suggests building on Normal Accidents Theory [84]. According to Normal Accidents Theory, there are two main characteristics of systems — complexity and coupling — that contribute to incidents and accidents. Complexity denotes the number of components that make up a system, including people, groups, and technologies. Coupling denotes the interconnectivity (in space, time, or otherwise) between the components that make up the system. The theory posits that in systems where catastrophic events are possible, highly complex and tightly coupled systems have a higher, if not inevitable (or "normal"), risk of unintended outcomes or system failures. Highly complex, tightly coupled systems cannot easily withstand the impact of an unexpected occurrence (e.g., due to performance failure of a fatigued individual), because other parts of the system must react immediately. The

effects can snowball and, due to high complexity, results in loss of predictability and manageability in many or all aspects of a system. Furthermore, anticipation of risk is predicated on the ability to predict system behaviors and outcomes. This is a challenge in highly complex, tightly coupling systems, which are thus associated with increased risk exposure for an organization.

Normal Accidents Theory provides a potentially useful way to think about the incorporation of teams in FRMS. The "Swiss Cheese Model" foundation for FRMS emphasizes redundancy. However, from the perspective of Normal Accidents Theory, redundancy may increase coupling and complexity, which may actually increase risk rather than safety [83]. Given the inherent complexity of 24/7 operations, the ideal environment for FRMS would be connected in a way that is neither too loose to be manageable nor too tight to be vulnerable. Teams and their characteristics (size, composition, roles, etc., as described previously) could be considered a means to control the degrees of complexity and coupling of an organization – thereby providing a strategy to manage fatigue risks in addition to, and to some extent orthogonal to, the redundancy of layers of protection called for by the "Swiss Cheese Model" [84]. Organizations could take readily steps to harness this strategy, for example by designing work spaces and the regulatory environment to encourage team work. That said, optimal use of this approach would require new research to better understand the dynamics of teams and organizations as systems.

## Pivotal role of teams in understanding and managing the consequences of fatigue

Whereas fatigue can have major consequences for organizational outcomes (productivity, safety, and profitability), efforts to mitigate the effects of fatigue are predominantly aimed at detecting and preventing or mitigating fatigue at the level of individuals, not teams. In part, the focus on individuals is a result of the difficulty in assessing and managing the functioning of a team beyond that of the separate individuals in the team. And in part, it follows from how organizations, and society in general, tend to deal with rewards and accountability. Teams are not commonly the specific target of rewards and accountability. Rather, rewards (such as salary and promotion) are bestowed upon individuals based primarily on their personal contributions to the organization. Accountability is usually assigned to designated individuals in the context of their organizational role and responsibility (e.g., leadership position). Not surprisingly, efforts to understand and manage fatigue have historically focused on individuals as well, with HOS regulations and fatigue countermeasure strategies pertaining to people as independent entities rather than as teams – even though the dynamics of teams and their operational functioning may have greater impact on the organization as a whole.

A systems-level understanding of fatigue and the role of teams with regard to fatigue would provide a novel platform for fatigue management design and decision-making. Research into teams would enable better prediction of the potential flow-on effects of a fatigued individual (or individuals) within a system, as well as the usefulness of fatigue control measures such as sending someone off duty or changing their work tasks. Notably, some people are more integral to the functioning of a team or system than others. The level of influence of each person within the team can be described through factors such as team context (e.g., structure, leadership roles) and team affective states (e.g., cohesion, trust) [10,85]. In a larger system, this can be conceptualized as centrality – certain people will be more centralized, and exert more influence on others. Taking out a highly centralized person could significantly destabilize a system, but an effective team structure may help to reduce the degree of coupling in the system and thereby mitigate the impact of centrality.

The current absence of team-level considerations in fatigue management is an important gap, especially since many of the necessary conditions for successful fatigue management rely on interactions between people and teams. Changes in behavior at a team level could act as a fatigue countermeasure, but there is also the potential for such changes to increase risk in a highly interdependent team system (e.g., not completing one's own tasks while engaging in backup behavior for a fatigued teammate, not communicating adequately [86]). A better understanding is needed of how these interactions and behaviors change in the context of the team as well as the larger organizational system, especially in highly complex and tightly coupled systems where small changes can have large, widely felt consequences.

In conclusion, fatigue affects individual safety and performance as well as organizational effectiveness. Most organizations encourage if not require team work, yet little is known about how fatigue affects teams and how teams affect fatigue outcomes. There is an urgent need to build the empirical knowledge base regarding the role of teams in fatigue risk management, through multidisciplinary research using established frameworks in the respective sciences of fatigue and teams. A better understanding of the underlying phenomena will form the basis for recommendations regarding the inclusion of team dynamics as part of comprehensive FRMS. The integration of team science into organizational-level fatigue risk management practices and policies is a formidable challenge, but given the importance of teams and team work in 24/7 operational settings, the importance thereof cannot be overstated.

**Practice points**

- Teams are in a critical, central position between individuals and organizations, but a largely overlooked component of understanding and mitigating the impact of fatigue on performance and safety outcomes.
- Compared to individuals, teams have greater potential to successfully self-monitor fatigue and provide protection against its adverse consequences.
- Multi-level study designs encompassing individual-, team-, and organizational-level effects that incorporate both qualitative and quantitative measures are needed to move this field forward.
- Established team models, such as the Input-Mediator-Output-Input (IMOI) model (Fig. 1), and applicable theories, such as Normal Accidents Theory, provide useful frameworks for understanding and managing the impact of fatigued individuals on teams and organizations. These frameworks may complement extant perspectives on fatigue risk management such as Reason's "Swiss Cheese Model" and fatigue risk management systems (FRMS).
- Organizations would do well to acknowledge and embrace the role of teams and team processes as part of a FRMS. For example, a FRMS could incorporate a process to facilitate team supporting behavior, such as monitoring teammates, enable non-punitive reporting of teammate impairment, and encouraging team workarounds to compensate for a teammate's diminished capacity due to fatigue.

**Research agenda**

Teams could be used to provide additional levers for fatigue prevention and fatigue risk management. Focusing on teams provides an opportunity for better outcomes at the individual level (e.g., fatigue, performance, health, and well-being) as well as at the organizational level (e.g., safety, productivity, and profitability). To take advantage of this opportunity, a number of knowledge gaps need to be addressed:

1. There is inadequate knowledge about how fatigue impacts team-level processes and how the team itself contributes to the fatigue of its constituent members. Well-established team frameworks such as the IMOI model provide a foundation for generating testable hypotheses and building an empirical knowledge base on the effects of fatigue in teams.
2. Even with a focus on teams, the contributions of individuals and their inter-individual differences must be considered. To this end, an evidence-based understanding of individual- and team-level differences in vulnerability and resilience to fatigue and subsequent effects on team and social processes and outcomes is critical.
3. It is not known how fatigue and team effects on performance outcomes affect organizations over repeat team performance cycles, or how regulatory and/or organizational fatigue risk management policies and practices affect team processes and outputs. Consequently, it is also unknown how best to leverage teams to make organizational fatigue management approaches more effective. There is a need for research on how organizations influence teams and how individuals and teams influence organizations in the context of 24/7 operations and the fatigue that is commonly associated with such operations.

Addressing these knowledge gaps calls for the integration of fatigue science with team science and a highly multidisciplinary research approach. Fatigue and team scientists may form partnerships to leverage the best research methodologies of each field. Conducting team research is inherently challenging and resource-intensive, as is fatigue research. Coupling these challenges with the additional need to examine both acute and chronic effects requires careful attention to sound experimental design, but could be exceptionally impactful when done well.

## Author contributions

PGR, SB, LBL, and HVD conceived the project. SB, LBL, HVD, JD, LBW, PGR, and SAC wrote the paper.

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