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COMMENTARY

What Control Measures Should I Use? Applying the *Total Worker Health* Hierarchy of Controls to Manage Workplace Fatigue

Imelda S. Wong[1] | Drew Dawson[2] | Sudha Pandalai[3] | Madeline Sprajcer[2]

[1]Centers for Health, Work & Environment, Colorado School of Public Health, CU Anschutz, Aurora, Colorado, USA | [2]Appleton Institute, CQUniversity, Wayville, South Australia, Australia | [3]Division of Science Integration, Centers for Disease Control and Prevention/National Institute for Occupational Safety and Health, Cincinnati, Ohio, USA

Correspondence: Imelda S. Wong (imelda.wong@alumni.ubc.ca)

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ABSTRACT

Increased fatigue risk has been associated with safety-critical events such as work-related injuries. While control measures are needed to reduce these risks, the wide range and complexities of fatigue risk management strategies can make it difficult for organizations to prioritize efforts given limited resources and time. Given these challenges, the aims of this commentary are two-fold. The first is to conceptualize fatigue risk management strategies within the *Total Worker Health* (TWH) Hierarchy of Controls, a conceptual framework used to prioritize strategies to advance worker safety, health, and wellbeing. As an extension to the traditional Hierarchy of Controls, the TWH version presents strategies in order of effectiveness, ranging from "eliminate," "substitute," "redesign," "educate," and "encourage" categories. The second aim of this paper is to use the TWH Hierarchy of Controls to identify control measures which reflect the level of fatigue risk for adverse safety and health outcomes.

Introduction

In recent decades, industries and organizations worldwide have become increasingly aware of the detrimental effects of fatigue on worker performance and safety [1]. The National Safety Council has described fatigue as "a debilitating and potentially deadly problem affecting most Americans," and estimates the annual cost to employers is approximately $136 billion annually due to fatigue-related errors, incidents, and lost productivity associated with shift work, sleep disruption, and sleep disorders [2]. While fatigue is mostly commonly associated with working time arrangements that result in inadequate sleep and circadian disruption [3–5], it can also be attributed to other occupational factors such as stress, monotonous tasks, dim lighting, certain chemicals, exposure to extreme temperatures and high workload [6].

The effects of fatigue are well documented. For example, it can impair cognitive functioning, such as shortening attention spans and concentration, with ultimate effects on work performance and productivity [7–10]. Studies have demonstrated that fatigue can double the risk for safety-critical events such as work injuries [11, 12]. A recent meta-analysis of 14 studies reported that risk for motor vehicle crashes increases by 30% when fatigue was present [13]. Human fatigue has been also cited as a causal factor in high-profile disasters such as the train

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derailment and explosion at Lac-Mégantic, Canada, which resulted in the spillage of 6 million liters of petroleum crude oil, destruction of 40 buildings, and 47 fatalities. The downtown area and nearby waterways were also contaminated, necessitating environmental clean-up efforts costing nearly Can$95 million, in 2014 [14].

Contributors to fatigue have also been explored by Di Milia et al, and attributed to many work and nonwork related factors [6]. Work-related factors include, but are not limited to, shift structure (e.g., shift type and duration, fixed or rotating shifts, speed and direction of rotation, recovery within and between shifts), physical and mental job demands, environmental exposures (e.g., extreme temperatures, chemical or biological agents), job stress and strain, commuting time and having multiple jobs. Factors related to demographics and biology include age, sex, health status, socioeconomic status, chronotype, and need for sleep. Examples of health behaviors and lifestyle factors contributing to fatigue include dependency care, use of alcohol/drugs, medications, exercise, and diet. Because of all these contributing factors and individual variability with respect to fatigue, it can be difficult to manage or mitigate.

To address fatigue-related occupational health and safety risks for accidents and injuries, occupational health societies, such as the American Conference of Governmental Industrial Hygienists, have recognized the need to implement control measures to ensure worker health and safety [15]. Organizations are also increasing efforts in this area, including fatigue mitigation measures within their safety management system framework [16]. This has been referred to as a "risk-based" model of fatigue management which focuses on the assessment of risks, rather than only the implementation of work hour limits [17].

Organizations such as the American National Standards Institute (ANSI) Z590.3/2021 define risk as an "estimate of the probability of a hazard-related incident or exposure occurring and the severity of harm or damage that could result" [18]. Identification or quantification of risk can help organizations decide on appropriate control measures that reflects the level of risk. Considerations for controls can include level of implementation (e.g., sector, organizational, worker) and type of effort (e.g., regulation, procedures, education) [19–21]. Moreover, controls can be categorized as primary or secondary [22]. Primary controls generally aim to reduce the likelihood that fatigue will occur. For example, limiting the number of work hours that can be undertaken consecutively would be considered a primary control as it would limit both sleep loss and workload—thereby generally reducing the likelihood of fatigue occurring. Conversely, secondary controls can be conceptualized as managing fatigue once it has occurred. For example, the strategic use of caffeine or scheduled rest breaks can be considered secondary controls—used when fatigue is identified at the individual worker level.

One method to quantify risk is with a risk matrix which "categorizes combinations of probability of occurrence and severity of harm, thus establishing risk levels ... to assist in comparing and prioritizing risks, and in effectively allocating mitigation resources." [23] The matrix is best described as a table with likelihood of a hazard occurring along one axis, and the severity of harm should the hazard occur, on the other axis. The combination of the likelihood of the hazard and the severity of harm is then assigned a value that indicates the level risk (e.g., low, medium, high) to help identify type of action to reduce the risk [24]. An example of a risk matrix is from United States Federal Aviation Administration Order 8040.4B, Safety Risk Management System (Figure 1) [25].

Once a risk score is established, considerations for different type of risk management controls can be considered, which include level of implementation (e.g., sector, organizational, worker) and type of effort (e.g., regulation, procedures, education) [19–21]. However, given the wide range and complexities of fatigue mitigation strategies, it can be difficult for organizations to prioritize efforts given limited resources and time.

This commentary is presented in two parts. The first part aims to conceptualize fatigue risk management strategies within the hierarchy of controls (HoC), a well-known occupational health and safety framework used to determine actions to best control hazardous exposures [26]. The second part of this article is to use the HoC to identify control measures which reflect the level of fatigue risk for adverse outcomes such as accidents and injuries.

Re-Envisioning Managing Fatigue Risk With the HoCs

The HoC is a risk management framework commonly used to categorize the effectiveness of controls for exposure to workplace hazards. It describes "five levels of actions to reduce or remove hazards," from most to least effective, in minimize exposure and/or harm to workers [26]. These levels include elimination, substitution, engineering controls, administrative controls, and personal protective equipment (PPE). However, the approaches of the traditional HoC were developed to address traditional physical, chemical, or biological hazards. Because of the complex nature of fatigue, most levels from the traditional HoC are not applicable. For example, fatigue is best described as being on a continuum and existing in some degree among individuals [27]. Thus it is not possible to eliminate or remove it from the workplace. Substitution in the traditional HoC, refers to "using an alternative to the hazard" [26]. Applying this definition in reference to fatigue does not make any sense (i.e., "using an alternative to fatigue"). Engineering controls are meant to "isolate the worker from the hazard" [26]. Again, because fatigue exists in some degree among all individuals, it is not possible to isolate the worker from fatigue. Similarly, it is unclear what, if any, PPE is effective to manage occupational fatigue. Among all levels from the traditional HoC, Administrative controls (i.e., establishing practice to reduce exposure to the hazard) is the only one that can be applicable to fatigue.

We suggest that the recently developed Total Worker Health HoC (hereinafter referred to as TWH HoC) may be a more appropriate and applicable framework to categorize control measures related to occupational fatigue [28]. This applied model serves as a companion to the traditional HoC model and "emphasizes organizational-level interventions to protect

Severity / Likelihood	Minimal 5	Minor 4	Major 3	Hazardous 2	Catastrophic 1
Frequent A	[Green]	[Yellow]	[Red]	[Red]	[Red]
Probable B	[Green]	[Yellow]	[Red]	[Red]	[Red]
Remote C	[Green]	[Yellow]	[Yellow]	[Red]	[Red]
Extremely Remote D	[Green]	[Green]	[Yellow]	[Yellow]	[Red]
Extremely Improbable E	[Green]	[Green]	[Green]	[Yellow]	[Red] * / [Yellow]

High Risk [Red]
Medium Risk [Yellow]
Low Risk [Green]

* High Risk with Single Point and/or Common Cause Failures

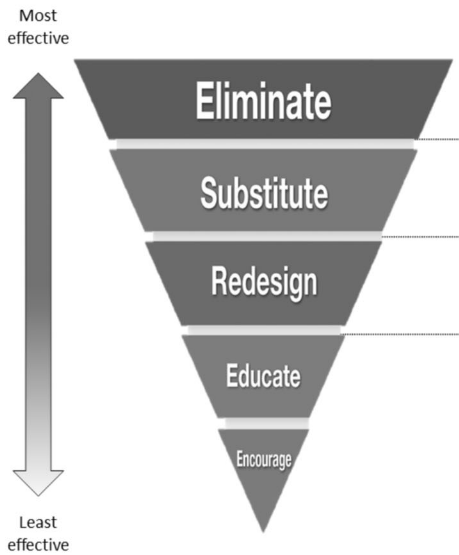
FIGURE 1 | Risk matrix—commercial operations/large transport category. *Source:* United States Department of Transportation, Federal Aviation Administration National Policy Order 8040.4B. Effective date: 05/02/2017 [25].

workers' safety, health, and well-being" [28]. Furthermore, the TWH HoC was developed to link traditional Occupational Safety and Health approaches (such as the traditional HoC) with *Total Worker Health* (TWH) concepts to advance worker well-being, which include control of traditional hazards and exposures (e.g., chemical, physical agents, biological agents), work organization (e.g., fatigue and stress prevention), built environment supports, leadership, compensation and benefits, community supports, changing workforce demographics, policy issues and new employment patterns [29]. While both models identify 5 levels of controls ranging from greatest to least effectiveness, there are a few significant differences. Rather than focus on controlling the hazard itself, TWH HoC focuses on controlling factors in the work environment that contribute to workplace hazards. It also combines Engineering and Administrative controls into "Redesign," and replaces "Personal Protective Equipment" with more broadly based "Education" and "Encouragement" strategies to facilitate behavioral change (Figure 2).

A recent qualitative study has documented the successful implementation of the TWH HoC to manage fatigue across different organizations [30]. A description of each level of the TWH HoC and its application to managing occupational fatigue is described below.

Strategies to "eliminate" hazardous working conditions are considered to be the most effective measures to address worker safety, health, and well-being [28]. In situations with extreme risk for immediate adverse effects, eliminating hazards that contribute to work-related fatigue could include eliminating working time arrangements associated with high fatigue risk (e.g., long work hours, overnight shifts, and many consecutive shifts) [20, 21]. However, for occupations such as emergency responders and some healthcare workers, working at all hours and sometimes for prolonged periods is a necessity to provide services. Other occupations, such as those in some mining operations, may regularly be exposed to extreme temperatures, dim lighting, or physically demanding labor which can contribute to high fatigue risk [31]. Therefore, elimination of common exposures in these circumstances may not be feasible.

"Substitute" in the TWH HoC refers to substitution with health-enhancing policies, programs, and practices [28]. One example would be to replace compliance-based strategies such as work hour limits with risk-based management practices such as



Definition	Examples to reduce work fatigue
Eliminate working conditions that threaten safety, health and wellbeing	Eliminate work schedules associated with high fatigue risk
Substitute health enhancing policies, practices and programs to minimize hazard or simplify complexity	Substitute decision burden with fatigue risk management systems, journey management systems and/or fatigue detection technologies
Redesign work environment and the work practices through engineering and administrative controls	Improve the built environment through lighting, ventilation or noise reducing strategies; Adjust work scheduling and tasks
Educate for safety and health; encourage personal change	Provide sleep and fatigue education and training for workers, managers and employers to encourage behavioural and organization change

FIGURE 2 | Total Worker Health Hierarchy of Controls with examples of controls of fatigue management strategies.

Fatigue Risk Management Systems (FRMS). FRMS have been described as a set of management practices for identifying and controlling fatigue-related risks that have been adapted to the organization or industry [16]. A recent systematic review found that FRMS "are likely to be effective" to improve safety and worker wellbeing, particularly among organizations where there are sufficient resources and a strong safety culture [32].

Substitution strategies have also been described as methods to "minimize hazards" and "simplify complexity" in the system [18]. An example would be using journey management systems to reduce transportation-related risks such as motor vehicle crashes. This involves formal procedures and policies to identify if there is a need for travel, assess potential risks across the planned trip, and develop pre-determined steps to minimize hazards. Pre-establishing policies and procedures before a motor vehicle trip will help lessen the decision burden on drivers and fleet safety managers with changing conditions during the trip (e.g., adverse weather events, road closures).

"Redesign" applies to using changes in the work environment to improve workers safety, health, and wellbeing. Controls can be further categorized as "engineering" which include modifications to the work physical environment, or "administrative" which address changing work practices or the way people work [26]. Examples of effective engineering controls to reduce fatigue and improve alertness include strategies to alter lighting and ventilation or reduce noise exposure [20, 21, 33–36]. Administrative controls include redesigning work schedules or job tasks/procedures to reduce fatigue risk over the course of shift or over successive shifts [19, 37]. Fatigue-proofing strategies could also be considered as another administrative method to reduce work fatigue [38]. Examples include the use of both verbal navigation commands and hand-signals in marine pilots during times where fatigue may be likely, or the use of double-checking instructions via phone when on-call doctors are woken from sleep [38]. Such approaches are appropriate when the risk is moderate for an accident or injury outcome.

Fatigue detection technologies can be categorized as both *substitute* and *administrative* measures. As a *substitute* control, technologies can simplify or minimize complex decisions to identify when someone is too fatigued to work safely. Prior studies have also identified use of technologies as a method to substitute unhealthy working conditions with safer ones [30]. For example, technologies can help identify when work should cease or change when the fatigue risk is too high to work safely. This can be achieved based on performance/biological monitoring (e.g., vehicle performance such as harsh braking, or physiological monitoring of eyelid droop). Technologies can be considered as an *administrative* control when the alert (e.g., audio or visual signals) signals to the worker to cease or change the way they are working to prevent a fatigue-related incident [39–41]. It must also be noted that the use of these technologies would generally require associated policies and procedures to ensure worker privacy and effective operation (rather than implementation in isolation) [42].

"Educate" and "encourage" strategies are situated at the bottom of the TWH HoC and considered to be the least effective measures at improving worker health and wellbeing in situations without an extreme, high, or moderate risk of an immediate outcome due to fatigue. However, these strategies are still important methods. Recent reviews report that fatigue education and training programs improved self-rated fatigue, personal safety, stress and burnout, and sleep quality [43, 44]. Programs ranged in length of time over which education/training occurred and in content, and included strategies that could be implemented during work (e.g., participating in discussions about fatigue risk) and outside of work (e.g., developing a regular pre-bedtime routine). Three common findings on program effectiveness emerg. First, administration of one-time education programs may not facilitate long-term behavioral changes needed to improve health behaviors [19]. Second, education coupled with personal change strategies may be more effective at improving sleep behaviors and sleep than education alone [19]. Reviews have suggested that repetition of information and adoption of personalized, small behavioral changes over time are effective to encourage adoption of healthier behaviors [45–47]. Third, combining education and training with other fatigue risk management strategies (e.g., work scheduling) permits a more comprehensive, systems approach to managing fatigue [37, 48].

While many effective fatigue risk management strategies have been identified in recent literature [16, 20, 21], their categorization into the HoC still needs further exploration. In addition, not every control measure will be effective or applicable in every industry or organization. As such, discussions among management, health and safety professionals, and labor representatives would be beneficial to identify suitable control measures for the specific organization or industry.

Selecting Control Measures Using the Hierarchy of Controls to Reflect Level of Fatigue Risk

As previously described, risk is a function of the likelihood and consequence of a hazard [49]. Likelihood refers to the possibility of the hazard (i.e., the potential source of harm) causing actual harm [50]. In the case of fatigue, its likelihood can depend on personal, occupational, organizational, and other environmental factors. The consequences of fatigue, can be immediate, such as accidents or injuries, or occur over longer time frames, with differing amounts of severity of morbidity or mortality.

Quantification of fatigue risk has been illustrated in several fatigue risk matrices. One example is the “Guidance for Managing Worker Fatigue During Disaster Operations”—a collaborative effort across several US federal agencies that provides guidance on managing fatigue during emergency responses during large-scale disasters [51, 52]. This report summarizes literature on the effects of working extended hours and suggests fatigue mitigation controls. Likelihood and consequence ratings were developed in consultation with subject matter experts and includes exposures to other known hazards that might contribute to occupational fatigue (e.g., nature of work involved, site conditions, living conditions, and emotional stress). Other examples of fatigue risk matrices include “Fatigue Management Guide for Airline Operators” from the International Air Transport Association, International Civil Aviation Organization, and International Federation of Air Line Pilots' Associations; and “Fatigue risk management systems for health service workers” recently developed by Queensland Health [53, 54].

We propose that TWH HoC can also help identify control measures to reflect the level of fatigue risk (Figure 3). Low fatigue risks may require control measures only at the lower end of the TWH HoC (i.e., educate and encourage). Moderate fatigue risk may necessitate the addition of “redesign” approaches. Extreme or high risks may warrant more stringent (i.e., “eliminate,” “substitute”) and/or a complement of control measures from multiple TWH HoC levels. A study among agricultural workers has demonstrated that implementation of a series of controls from several levels was associated with a decreased risk for work injury [55].

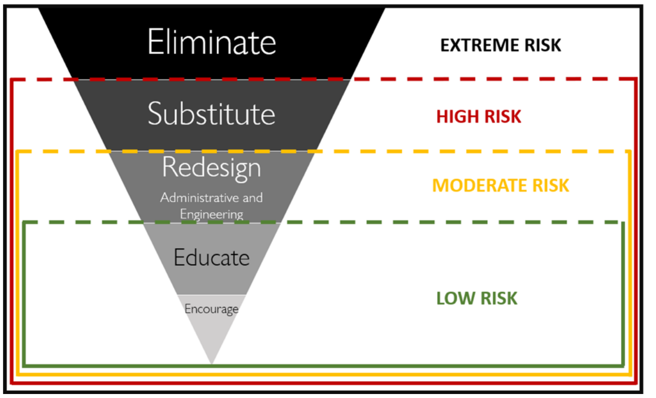


FIGURE 3 | Identification of control measures based on level of fatigue-related risk (risk being determined via a combination of likelihood and consequence).

Depending on the industry or organization, there may some flexibility or leeway between the suggested control level and risk level. For example, where a moderate fatigue risk is identified, an organization may choose to implement a higher-level control measure such as an FRMS (*substitute* control) given the potential for improvements in organizational safety and operational flexibility [32]. Following a TWH approach, implementation of different methods which address work and nonwork factors associated with similar or overlapping adverse effects could have relevance for holistic intervention and prevention strategies targeting fatigue.

Decisions regarding control measures may also involve other considerations such as feasibility and cost. The higher levels of the TWH HoC (*eliminate* and *substitute*) have been described as those instituted at the highest tier of the organization and would generally be associated with an increased need for organizational resources [30]. For example, eliminating overnight schedules or implementing fatigue detection technologies may require significant time and resource investment [30]. This may include engaging subject matter experts, forming and using dedicated teams, or implementing large-scale changes to standard operational practices. With each successive tier in the TWH HoC, control measures are less organization-based and more focused on the individual [30]. For example, implementing an educational program to encourage behaviors to manage fatigue, might involve personalized goal setting in combination with peer-led meetings. Thus, choosing appropriate controls to manage work-related fatigue can involve a balance between effectiveness and feasibility. From a TWH perspective, risk management strikes a balance between organization- and individual-based strategies, which aligns with a multi-systems approach noted in other work [42].

Limitations and Future Directions

Using the TWH HoC to manage fatigue risk is not without limitations. Determining control measures based on the level of risk can be unique to industries and organizations, given that much of risk assessment is based on perspectives about the likelihood or consequences of a hazard within an established framework. Assigning control measures across TWH HoC levels is therefore intended to support organizations to conceptualize appropriate control measures based on fatigue-related risk, without being prescriptive. It has been suggested that the sequence of controls should not be considered as a "hierarchy" but rather as a "series of options, the importance of which might vary depending on the ... task or process involved." [55] This has been similarly illustrated with Reason's "Swiss Cheese" model of accident causation [56], and by extension, Dawson's fatigue risk trajectory model [16]. The fatigue risk trajectory model involves "levels" along the error trajectory, including hazards to be assessed and potential controls at each level. These levels start at the broad worker population level and narrow towards the actual error occurrence. Level 1 refers to sleep opportunity, with associated controls including prescriptive hours of service rules, aggregate prior sleep wake modeling, and other fatigue modeling. Level 2 refers to actual sleep obtained, with the monitoring of prior sleep wake data used as a control. Level 3 refers to behavioral signs and symptoms of fatigue, with controls including symptom checklists, self-reports, and physiological monitoring. Level 4 refers to fatigue-related errors, with fatigue-proofing strategies as potential controls [38, 57]. The final "level" is the actual incident itself. Dawson and McCulloch [16] identified levels of error trajectory for fatigue that are useful and practical, despite being somewhat arbitrary—much like the HoC and TWH HoC. Although the conceptual framework described in this present paper has limitations, we would suggest that where possible, organizations should take a more cautionary approach by providing additional, rather than fewer, control measures. Additionally, we suggest incorporating the TWH HoC approach would be best implemented in a systematic manner, while keeping an awareness of the limitations of different control measures.

Future considerations to manage work-related fatigue could include concepts from other HoC models, such as the Psychosocial Safety Climate Hierarchy of Controls (PSC-HoC), as this tool is specifically aimed at addressing psychosocial hazards such as job strain (i.e., high demands and low control) and depressive symptoms—factors which have been identified as contributing to fatigue [58–63]. Unlike the traditional HoC, the PSC-HoC is based on PSC theory principles that can be used to address identified psychosocial hazards. Strategies are described in five levels which include Organizational Workplace Policy and Procedures (Level 1), Human Resource Management, Injury Prevention, Injury Management, Organizational Development, and Workforce Health and Safety Units (Level 2), Manager, Supervisor, and Team Leader Actions, and Support (Level 3), Job Design (Level 4), and Individual Factors (Level 5). The PSC-HoC has been used successfully to benchmark organizational PSC, however, its effectiveness at fatigue mitigation is unclear. As such, future studies are needed to explore the effectiveness of the PSC-HoC at reducing work-related fatigue.

While we have identified use of current fatigue detection technologies as possible method to manage fatigue risk, they also may create additional control measures and challenges. For example, adoption of automated and assisted technologies, such as autonomous vehicles and robotics, have been adopted in some sectors (e.g., mining, aviation) [64]. However, level 3 automated vehicles still require some level of oversight from their driver to take control of the vehicle in the event of an emergency [65]. It is worth noting that a recent review reported that driver fatigue is associated with poor takeover performance in drivers [65], largely due to the fatiguing effects of monotonous continual-monitoring tasks [66]. As such, while the introduction of autonomous vehicles may reduce the overall fatigue-related risk by reducing the time spent undertaking high-consequence tasks (i.e., driving), there may be an elevated likelihood of incident severity in emergency situations (i.e., where the driver must take over the vehicle).

Conclusion

While the traditional HoC has commonly been used as a framework to control exposures to protect workers, it may not be easily applied to manage fatigue, as fatigue is ubiquitous and always present [27]. As such, we propose the TWH HoC may be more appropriate to mitigate occupational fatigue risk because it identifies control measures which address work conditions and environments contributing to fatigue. This framework can be an effective method for not only identifying priorities and effectiveness of control measures, but also could be used to scale efforts based on relative fatigue risk.

Author Contributions

Imelda S. Wong, Drew Dawson, and Madeline Sprajcer conceptualized the topic, wrote the initial draft, and reviewed all subsequent revisions. Sudha Pandalai reviewed and revised subsequent versions.

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The authors have nothing to report.

Data Availability Statement

The authors have nothing to report.

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