

WORKtoZERO
an nsc program



Wearables for Fatigue Monitoring

Executive Summary

Fatigue can have debilitating effects on workers, both at their worksites and on the road. People often underestimate how vital adequate sleep is for their response time, mental acuity and physical condition. More than 43% of U.S. workers are sleep-deprived, and those most at risk work the night shift, long shifts or irregular shifts. Additionally, fatigue can cost employers \$1,200 to \$3,100 per employee annually (NSC, 2019).

In 2020, the Work to Zero initiative at the National Safety Council released its first white paper detailing the top 18 hazardous workplace situations related to serious injuries and fatalities. In this research, fatigue has been identified as an underlying, or systemic, risk factor in serious injuries and fatalities. The Work to Zero initiative looks towards leveraging technology to eliminate workplace fatalities. This report looks at utilizing wearables for monitoring worker fatigue and impairment.

Fatigue monitoring wearables are wearable devices that use a range of sensor technology or visual cues to accurately assess a worker's fatigue and impairment levels. Three common types of monitoring capabilities include electroencephalography (EEG) sensors to monitor brain activity relative to fatigue, monitoring for visual cues and microsleeps, and using sleep and activity data to calculate fatigue risk levels.

Fatigue monitoring wearables have seen growing use in high-risk and machine-heavy industries like manufacturing, mining and construction. Successful implementation of fatigue monitoring wearables have demonstrated that meaningful fatigue-related safety data can be collected by an employer in a cost-effective manner without interfering with a worker's daily routine, and they can provide granular insights into previously unknown worker risks. While benefits point towards the value of fatigue monitoring wearables, companies should consider the potential barriers in worker uptake due to privacy concerns on the personal data that can be collected.



Introduction and Background

Work to Zero

Despite concerted efforts to reduce serious injuries and fatalities (SIF), workplace fatalities have not seen a drastic reduction in the U.S. Between 1992 and 2017, the OSHA (Occupational Safety and Health Administration) recordable injury rate dropped from 8.9 injuries per 100 workers to 2.8 injuries per 100 workers, a 67% decrease (National Safety Council, 2018). In the same time span, the workplace fatality rate (preventable fatalities) only dropped 26%, with 4,414 preventable workplace fatalities in 2017 (Bureau of Labor Statistics, 2018). Additionally, 5,250 total fatal work injuries were recorded in the U.S. in 2018, a 2% increase from the 5,147 in 2017, according to the U.S. Bureau of Labor Statistics. Between 2017 and 2018, the fatal work injury rate remained unchanged at 3.5 per 100,000 full-time equivalent workers. The expansive efforts by companies to reduce workplace injuries do not seem to translate into impactful reductions in workplace fatalities.

Recognizing this trend, the National Safety Council (NSC) kicked off its Work to Zero Initiative in 2019 – supported by a grant from the McElhattan Foundation – to focus on combatting the lagging decline in workplace fatalities and serious injury events. The end goal of the Work to Zero initiative is to eliminate workplace fatalities through the use of technology. Using decades of insight and data, and leveraging the expertise of NSC members and networks, Work to Zero will identify promising technology innovations geared toward eliminating workplace fatalities within our lifetime.

Digital Technology as an Approach to Reducing Workplace SIF Events

In 2020, the Work to Zero initiative released its first white paper detailing the top 18 hazardous workplace situations (e.g. work at height, machinery operation, confined space entry) and associated situational risks (e.g. falls, struck-by, hazardous gas exposure). The report further identified the systemic contributing factors (e.g. lack of training, fatigue, work design) that can exacerbate risk within these hazardous situations. Next, NSC worked with Verdantix researchers to identify over 100 relevant EHS technologies that could help mitigate both situational and systemic risks. These risks were also mapped in ways that surveyed EHS professionals perceived to be most effective.

The initial Work to Zero report identified several key technologies that garnered the most interest and value among the surveyed professionals. In addition, safety leaders within the Campbell Institute at NSC have demonstrated interest in assessing and evaluating certain technologies, such as virtual reality, wearables, sensors and unmanned aerial vehicles (drones). This report is one in a series of reports taking a more focused look at specific hazardous risks and associated promising technologies.

Specifically, this report will look at the use of wearables for fatigue management. It will cover the various use cases associated with fatigue monitoring wearables. Additionally, it will explore the identified and proposed benefits of this technology, as well as the limitations and risks associated with adoption. Finally, this report will shine some light into the vendor landscape associated with fatigue monitoring wearables to provide education on the market and offerings.



The Effects of Fatigue at Work

Fatigue can have debilitating effects on workers, both at their worksites and on the road. People often underestimate how vital adequate sleep is for their response time, mental acuity and physical condition. More than 43% of U.S. workers are sleep-deprived, and those most at risk work the night shift, long shifts or irregular shifts. Following are a few facts about the impacts of fatigue at work (NSC, 2019).

Safety performance decreases as employees become tired:

- 62% of night-shift workers complain about sleep loss
- Fatigued worker productivity costs employers \$1,200 to \$3,100 per employee annually
- Employees on rotating shifts are particularly vulnerable because they cannot adapt their “body clocks” to an alternative sleep pattern

Fatigue has been identified as a contributing factor in some of the worst industrial disasters in history, including the 2005 Texas City BP oil refinery explosion, the 2009 Colgan Air Crash, the explosion of the space shuttle Challenger, and the nuclear accidents at Chernobyl and Three Mile Island. Fatigue also extends outside of the workplace and can have negative effects on a worker’s personal home life. A 2005 study, based on a survey of 2,737 medical residents, found that every extended shift scheduled in a month increased their monthly risk of being in a motor vehicle crash during their commute home from work by 16.2% (Barger, et al., 2005). Additionally, fatigue can affect workers’ long-term health, including increased risk of heart disease, depression and digestive problems.

The adverse health outcomes and high prevalence of fatigue in many industries has been well documented, but there has been limited research on the prescription of interventions or the visibility of technology to manage worker fatigue. Interventions to target fatigue contributors and systemic factors are key in preventing fatigue-related incidents. Wearable technologies can act as a supporting tool in identifying risk factors, developing intervention plans, and tracking metrics and indicators of success.

Research Approach

The methodology of this paper consists of two actions:

1) Identification of case studies, clinical trials and use cases for fatigue monitoring wearables

2) Development of a market landscape shortlist of relevant vendors associated with this technology

Data for this paper came from literature reviews of several academic and industrial journals related to this technology. Additionally, Verdantix researchers used case studies and interview data from previously published reports and interviews (Verdantix, 2020). The vendor shortlist was compiled through a search of Verdantix market databases and external research. Vendors were selected based on the size and maturity of the firm, relevance to risk areas, demonstrable use cases and applicability to the U.S. market. For the purpose of this paper, fatigue monitoring wearables are geared toward industrial use cases, thus those devices used for road safety have not been identified unless industrial use cases were also communicated.

Introduction to Wearables for Fatigue Monitoring

Fatigue monitoring wearables are wearable devices that use a range of sensor technology or visual cues to accurately assess a worker's fatigue and impairment levels. Unfortunately, there is no standardized assessment or definition of what worker fatigue means. Clinically, fatigue is defined as difficulty in performing voluntary activities. Fatigue is a broad concept, which includes mental, motor, metabolic, endocrine, sensory, and other physiological or environmental components (Trejo et al., 2015). For the purpose of this report, fatigue monitoring wearables refer to those that monitor for impairment, not those focused primarily on physical fatigue monitoring.

Types of Wearables for Fatigue Monitoring

Wearable technology can monitor fatigue in three separate ways:

- **Wearable devices that use electroencephalography (EEG) sensors to monitor brain activity relative to fatigue**
- **Wearable devices that use cameras to monitor visual fatigue cues, such as microsleeps and eye movement**
- **Fatigue monitoring that uses activity and sleep data from wearables to calculate potential impairment and fatigue levels**

EEG has historically been used to monitor brain waves for diagnosis of epilepsy and sleep disorders in a clinical setting, but is currently being studied and employed to monitor workers for fatigue. Changes in EEG analysis can signal the onset of stages of sleep, with studies also showing that EEG patterns can signal the onset of mental fatigue in people fully awake. For example, a separate analysis of data from this study found evidence for three statistically separable stages of mental fatigue development: an alert state, a normal state (neither alert nor fatigued) and a mental fatigue state (Trejo et al., 2015). Some vendors use this technology within their fatigue monitoring-solution offerings. SmartCap Technologies' LifeBand product, for example, uses head-mounted EEG sensors to monitor brainwave activity in real-time and alert workers and managers of irregular activity and indicators of reduced alertness.

The use of visual cues or behavior-based recognition of fatigue is another prevalent type of analysis of worker fatigue. Cameras and sensors can detect fatigue using an analysis of factors, including eye blinking, head movement, head tilt direction, retinal characteristics and eye movement (Varma, et al, 2012). Visual analytics have been used by the road transportation industries for years through in-cab cameras and associated analytic platforms. Recently, some vendors have moved from in-cab cameras to wearable devices to better capture worker visual cues in more compact and portable forms. For example, OptAlerts's drowsiness-detecting glasses measure eyelid movements up to 500 times per second and transmit this information to an onboard application to warn workers of potential fatigue.

The last common method of wearable fatigue monitoring uses sleep and vital sign data, sometimes called biomathematical modeling, as a means of predicting, preventing and mitigating fatigue-induced risks. Among the more mature and well-regarded fatigue models is the Sleep, Activity, Fatigue and Task Effectiveness (SAFTE) model. A 2008 report for the U.S. Federal Railroad Administration found that the risk of human factor-related incidents increased significantly during periods when SAFTE predicted fatigue-induced impact on a worker's performance (Hursh, Fanzone & Raslear, 2011). Subsequent analyses of 350 human factor-related incidents demonstrated the relative economic risk (accident probability x [material damage + casualty costs]) increased by 500% when SAFTE-predicted effectiveness scores were below baselines (Hursh, Fanzone & Raslear, 2011). Fatigue Science's Rediband uses wrist-worn activity monitors, either proprietary or commercially available options like Fitbit, to monitor SAFTE factors and display fatigue risk scores to help companies determine the priority of fatigue mitigation.

Example Vendors

Vendor
Caterpillar
Actigraph
Strongarm Tech
Fatigue Science
DorsaVi
OptAlert
SmartCap
MakuSafe
Vigo

Color Code
Monitoring through sleep and activity tracking
Monitoring through visual cues
Monitoring through EEG

Fatigue Monitoring Use Cases

Fatigue monitoring for workers in transport and road-related use cases have been the most prevalent solutions on the market over the last decade. Recently, wearables have begun to develop new functionality and form factors to support industrial use cases. Manufacturing has seen a steady rise in fatigue awareness among its workers and as a systemic risk factor in SIF events. A survey of 451 U.S. manufacturing workers found that 57.9% of respondents indicated they were somewhat fatigued during the past week. Advanced manufacturing has resulted in significant changes on the shop floor, influencing work demands and the working environment while the corresponding safety-related effects, including fatigue, have not been captured on an industry-wide scale (Cavuoto, L, 2018).

Mining and extraction industries stand to benefit from the adoption of fatigue monitoring wearables. Mining operations are often high-risk settings, with workers surrounded by machinery in hazardous environments. In open-pit mines, fatigue-related incidents account for up to 65% of truck driving crashes alone (Schmidt, 2015). Thus, many mining companies have developed fatigue management programs and training. Data collection from fatigue monitoring wearables acts as a valuable tool to enhance these initiatives. For example, Goldcorp equipped 1,000 workers at its Peñasquito polymetallic mine in Mexico with Fatigue Sciences Readibands to enable the proactive monitoring and mitigation of worker fatigue risk across its operations.

With machinery risks similar to mining, construction workers also face a high prevalence of fatigue-related risks. Common causes of construction worker fatigue include extended hours, night work and increased workloads. Similarly, physically demanding and repetitive work, which is the norm in construction, is a big contributor to construction worker fatigue. Another factor that leads to worker fatigue is environmental conditions, such as working in extreme heat or cold temperatures. A survey of 606 U.S. construction workers found that 49% reported being 'tired some days' in the past three months, and 10% reported being 'tired most days or every day' (Zhang, et al., 2015).

Ultimately, fatigue is present in any work setting and is driven by a variety of work-related and personal factors. All industries can benefit from investigating the applicability of fatigue monitoring wearables in their operations, ranging from high-risk oil and gas companies to retail-focused big-box chains.

Benefits of Leveraging Wearables for Fatigue Monitoring

The numerous risks associated with fatigued and impaired workers are highlighted extensively throughout this report. Companies can be best served by developing a fatigue management program using communication and administrative controls for intervention and control of worker fatigue. Leveraging wearables for fatigue monitoring provides these programs with the granular data needed to make informed and proactive decisions. A study on wrist, hip and ankle fatigue monitoring sensors demonstrated that meaningful fatigue-related safety data can be collected by an employer in a cost-effective manner without interfering with a worker's daily routine (Cavuoto, L, 2018).

Fatigue monitoring wearables can provide some surprising insights into previously unknown worker risks. For example, a large mining company used the Cat Driver Safety System (DSS), an in-cab fatigue and distraction monitoring and mitigation device, to monitor workers' physical signs and microsleeps. In its pilot test, DSS was installed in only five of the company's haul trucks and a 90-day, three-phase approach to quantifying fatigue risk and mitigating incidents ensued. To measure the scope of the problem, the company recorded microsleep events for the first 30 days but did not alert the operators. In that month, 63 fatigue events were recorded, and it was shown that operators traveled nearly one mile while sleeping. After this first month, the alarms in the first five trucks were activated to alert workers, and fatigue events diminished by 86% over the next 60 days.

Risk and Considerations in Using Wearables for Fatigue Monitoring

Barriers to Adoption

The allure of using wearables to monitor worker fatigue can be strong among companies looking to adopt the newest technology to combat a dangerous risk among their workforces. But there are some key considerations to recognize in the adoption of any new technology, especially wearable technology. Wearable technology can face barriers in worker uptake due to privacy concerns on the personal data that can be collected. In a survey of 102 EHS decision-makers, 65% of respondents said data privacy concerns were a significant barrier to their adoption of industrial wearable technology (Verdantix, 2019). Regulations such as the EU's General Data Protection Regulation (GDPR) and California Consumer Privacy Act (CCPA) have introduced new considerations for employers when managing worker data for all sources.

Data collection and wearable acceptance can vary drastically between workers based on demographics and experience. A survey in *Applied Ergonomics* of 1,273 employees found that when introducing a wearable, the optimal scenario appears to be the voluntary and incentivized implementation in which data is collected only at work to monitor and improve safety. The environment would have a strong safety climate, be unionized and have a low risk for employee termination. The employee population would be predominantly techno-curious, experienced with wearable technology and the direct supervisors would serve as relevant participants in data collection. The implementation can facilitate performance expectancy by communicating evidence that the wearable will meet its objective (i.e., the device would be proven effective), the employees would be involved in the process of selecting the device, and the program should clearly inform employees about why, how, and by whom the data will be used and protected (Jacobs, et al., 2019).

Limitations of the Technology

Wearable devices, as with many new mobile technologies, rely on some form of existing technical infrastructure. Industries with historically low connectivity, such as utilities, and oil and gas, face increased issues with ensuring reliable technical infrastructure. Similarly, industries like oil and gas, and chemical production, typically require intrinsically safe devices, which can severely limit the commercially available options for these businesses.

Fatigue monitoring using wearable technology is still a young market. Thus, the availability and scalability of this technology will be less than non-wearable alternatives, such as in-cab camera analytics. As an emerging market, wearables for fatigue can come with a high capital cost for the hardware and any associated analytics platform, if sold separately. As the market grows, more vendors offer solutions and supply chains strengthen, costs will lower to become more accessible for companies with lower discretionary budgets.

Conclusion and Future Direction

The goal of the Work to Zero initiative at NSC is to eliminate workplace fatalities through the use of technology. Initial research for Work to Zero undertaken by NSC shed light on the situational and systemic risks that play pivotal factors in workplace SIF events. Using expert interviews, NSC identified promising technologies to combat these high-risk activities. Of these technologies, fatigue monitoring wearables were of interest among survey respondents and NSC members.

Fatigue is a major issue across multiple industries, as fatigued workers are at increased risk of impaired judgment, microsleeps and behavior errors. Workplace fatigue is estimated to cost employers about \$136 billion a year in health-related lost productivity, and more than 70 million Americans suffer from a sleep disorder (NSC, 2020). Fatigue has been identified as a contributing factor in some of the worst industrial disasters in history, including the 2005 Texas City BP oil refinery explosion and the 2009 Colgan Air Crash.

Companies should investigate options for developing comprehensive fatigue management initiatives using training and administrative controls to recognize and act upon worker fatigue. Fatigue monitoring wearables can act as valuable tools in providing surprising insights to previously unknown worker risks through granular data and analytics. Fatigue monitoring wearables come in three different methods of deployment and functionality: wearables that use EEG and vital signs for monitoring, wearables that use cameras for behavior and visual cues, and activity-tracking wearables that analyze sleep and vital sign data to predict fatigue.

Each wearable option monitors fatigue in a beneficial way to help reduce workplace fatalities and saves resources lost in productivity disruptions and lost-time. While this technology offers exciting possibilities, considerations for worker data privacy and wearable acceptance must be acknowledged by potential implementers. Additionally, adequate infrastructure should be assessed before implementing wearable devices to ensure they fit IT requirements and policies.

Interest in wearable technology has grown despite facing major adoption barriers due to data privacy regulations. The market for wearables developed for fatigue monitoring is still in its infancy, with a range of smaller start-ups or niche vendors. Most use cases have focused on clinical or medical trials, sports training or military deployment. Over the next five years, the growing adoption of wearable technology and visibility into the risks of fatigue will help to introduce new entrants into the fatigue monitoring wearable market, lowering cost per device and strengthening supply chains.

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