WORKtoZERO
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Best Practices and the Use of Vital Signs Monitoring for Heat Stress Mitigation

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National Safety Council

Executive Summary

This white paper explores the use of vital signs monitoring wearables for Environment, Health and Safety (EHS) applications, and how they can prevent or mitigate serious incidents and fatalities (SIFs) in the workplace. When combined with other heat management strategies, these wearable technologies enable the active monitoring of workers' physiological responses, including heart rate, core body temperature and fluid loss, offering the potential to identify and alert to potential signs and symptoms of heat strain.

For workers, these immediate, actionable insights allow for self-regulation and the adoption of preventive measures against heat stress. For employers, aggregated data can be used to identify those areas or jobs most prone to strain or injury and inform the development of targeted safety protocols and interventions. Concerns regarding the collection of sensitive health information, cost and resource investments, and technological limitations have proven to be notable, though navigable, challenges to the widespread adoption of these devices.

Key Findings:

1. Heat stress poses a considerable risk to workers across various industries and organizations. Exposure to extreme heat can not only lead to an array of illnesses and injuries, but can also impact worker productivity, cognitive function, mental health and overall wellbeing.

2. Vital signs monitoring systems are currently considered to be in the "launch" phase of maturity and further research is needed to validate their use in industrial settings. However, preliminary studies indicate these systems can accurately track critical indicators of heat stress, including heart rate, core body temperature, fluid loss and corresponding environmental conditions.

3. The use of these technologies can benefit both individual workers and the broader organization. For workers, individualized insights can allow them to make informed decisions to reduce their exposure to heat and promptly address symptoms of illnesses or injuries. For employers, these data can be used to inform the organization's heat mitigation practices to proactively address related SIF risks.

4. Potential barriers to the widespread adoption of vital signs monitoring include a lack of validation and use cases for EHS applications, cost and resource limitations, and concerns regarding data privacy and security. Furthermore, vital signs serve as an indirect "proxy" for heat stress, rather than a direct measurement, and should not replace other strategies for heat mitigation.

With these benefits and considerations in mind, the use of vital signs monitoring can serve as a proactive approach for identifying and mitigating heat-related hazards in the workplace. To reduce investment risks and allow for continuous improvement, employers are encouraged to begin the process with small-scale pilots, targeting a limited number of employees or test locations. Engaging with workers across all levels of the organization and allowing end users to trial the technology can also facilitate this process by allowing them to ask questions, share concerns and provide valuable feedback. By holistically approaching workplace risks and prioritizing a human-centric approach to innovation, organizations can harness the potential of vital signs monitoring technologies to prevent SIFs in the workplace.

Introduction and Background

Work to Zero

Despite concerted efforts to reduce serious incidents and fatalities (SIFs), workplace fatalities have not seen a drastic reduction in the United States. According to the Bureau of Labor Statistics (BLS), between 1992 and 2022, the Occupational Safety and Health Administration (OSHA) recordable injury rate dropped from 8.9 injuries per 100 workers to 2.7 injuries per 100 workers, a nearly 70% decrease (BLS, 2023a). In the same period, fatal work injuries only fell by about 12%, from 6,217 fatalities in 1992 to 5,486 in 2022 (BLS, 2023b). Thus, the expansive efforts by companies to reduce workplace injuries do not seem to translate into impactful reductions in workplace fatalities.

Recognizing this trend, in 2019 the National Safety Council (NSC) launched its Work to Zero initiative, 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 at NSC is to eliminate workplace fatality risk through technology. Using decades of insight and data, and leveraging the expertise of its membership and network, Work to Zero identifies promising technology innovations geared towards eliminating workplace fatality risks within our lifetime.

In 2020, the Work to Zero initiative released its first white paper, detailing the top eighteen 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) (Work to Zero, 2020). The report went further and identified the systemic contributing factors (e.g., lack of training, fatigue and work design) that can exacerbate risk within these hazardous situations. Next, NSC worked with Verdantix researchers to identify over 100 relevant EHS technologies helpful in mitigating both situational and systemic risks. These technologies fall into one of 11 categories: analytics, content, data management, equipment, exoskeletons, mobile apps, PPE, robotics, sensors/detectors, software and wearables. Visit nsc.org/WorktoZero to access the full report.

Building on the foundational white paper from Work to Zero, this report explores the impacts of excessive heat stress on worker health and productivity, as well as an overview of strategies for managing occupational heat stress. Next, we look at the utility of vital signs monitoring technologies as a proactive approach to identifying and mitigating heat-related illnesses and injuries, drawing on a comprehensive review of academic and industry literature. Finally, we go into the potential benefits, risks and considerations for implementation, as well as additional guidance to navigate these challenges.

Research Approach

The methodology of this white paper consisted of three parts:

1. A comprehensive literature review of academic, industry and grey literature
2. Interviews with industry partners currently leveraging vital signs monitoring for managing occupational heat stress
3. The formation of a dedicated working group comprised of industry professionals

Data for this paper came from literature reviews of academic articles, industry reports and grey literature. A flexible research strategy was employed, utilizing multiple databases, including EBSCO, JSTOR, PsycINFO and the Verdantix research portal. The search strategy was limited to literature published within the last decade. A grey literature search for the same period was conducted using Google Scholar. The search strategy was based on the following iterations of the terms: (Vital Signs Monitoring OR Physiological Monitoring) AND (Heat OR Heat Stress OR Heat Strain OR Occupational Heat Stress) AND (Technologies OR Solutions OR Systems).

Next, semi-structured interviews were carried out with representatives from organizations currently utilizing, or with prior experience using, vital signs monitoring within their workplaces. These interviews were conducted to better understand the various use cases of the technology, explore its potential benefits and barriers to adoption, and share best practices gleaned from early adopters during the pilot and implementation process.

Finally, a dedicated workgroup consisting of industry professionals, solutions providers and subject matter experts was formed, which provided a platform for members to share their expertise and insights and provide feedback during the research process. This group met twice between January to March 2024, and all members had the opportunity to review the resulting white paper for accuracy and relevance to their respective fields.

Overview of Occupational Heat Stress

According to the Bureau of Labor Statistics (2023b), there have been a total of 479 heat-related workplace fatalities from 2011 to 2022. In 2022 alone, 43 workers lost their lives, marking a 19% increase from 2021. Workers are also experiencing heat-related injuries and illnesses at alarming rates. Between 2011 and 2020, an average of 3,389 workers experienced injuries or illnesses resulting in days away from work each year (OSHA, 2023). However, these figures are likely a vast underestimation due to the varying nature of heat-related symptoms, lack of consistent definitions and underreporting (OSHA, 2023). One study estimated environmental heat is likely responsible for a minimum of 170,000 injuries each year in the United States (Fulcher, 2022).

Nonetheless, the issue of occupational heat stress is a growing global concern, affecting virtually all industries and occupations. According to the Intergovernmental Panel on Climate Change, climate projections point toward an increase in the frequency and intensity of extreme weather events, including heatwaves and droughts. These climatic shifts will likely lead to an increase in heat-related SIFs, reduced occupational productivity, loss of jobs and significant financial impacts (Kjellstrom et al., 2019). As temperatures continue to rise and excessive heat becomes more prevalent, addressing heat stress in the workplace is imperative for safeguarding worker health, safety and overall wellbeing.

What is Heat Stress?

The National Institute of Occupational Safety and Health defines heat stress as *"the sum of the heat generated in the body (metabolic heat), plus the heat gained from the environment (environmental heat), minus heat lost from the body to the environment"* (NIOSH, 2016, p. 1). Heat stress results in a series of physiological responses within the body designed to regulate internal temperature (e.g., sweating, increased blood flow, vasodilation). This process, known as heat strain, is designed to promote the transfer of heat from the body back to the environment and regulate the body's internal temperature (Parsons, 2019). However, at elevated levels of heat stress, these compensatory mechanisms are no longer capable of maintaining the temperatures required for normal body functions, contributing to the risk of heat-related illnesses, disorders and other hazards increasing (NIOSH, 2016). Exposure to extreme heat can contribute to an array of SIF risks, including:

1. **Heat Cramps**, which manifest as involuntary, often painful muscle cramps or spasms resulting from depleted salt and moisture in the body (NIOSH, 2022a)

2. **Heat Edema**, which leads to swelling and possible discomfort in the distal extremities – workers may complain of tight gloves or shoes due to swelling of the hands or feet (Gauer & Meyers, 2019)

3. **Heat Exhaustion** is the body's response to excessive loss of water and salt, which presents as a range of symptoms including nausea, vomiting, dizziness, light-headedness, headache, thirst, weakness, excessive sweating, muscle cramps or decreased urine output (Leiva & Church, 2022)

4. **Heat Rash**, a type of skin irritation that occurs when sweat glands are obstructed, typically resulting from restrictive clothing or other occlusives (i.e., bandages) (Leiva & Church, 2022)

5. **Heat Stroke**, a life-threatening condition clinically diagnosed as a severe elevation in body temperature with central nervous system dysfunction often including combativeness, delirium, seizures and coma (Leon & Bouchama, 2015)

6. **Heat Syncope**, referring to temporary dizziness, weakness, or loss of consciousness during prolonged standing or movement in a hot environment (Leiva & Church, 2022)

Heat stress can also have indirect impacts on worker health and safety. Working in hot environments or exposure to hot machinery or equipment can result in sweaty palms, fogged-up safety glasses, or dizziness or disorientation, thereby increasing the risk of accidents and injuries (NIOSH, 2016). Complex cognitive tasks can also be impacted by heat stress and dehydration (Piil et al., 2018), which can be particularly concerning for workers performing skilled and potentially dangerous work (Morrissey et al., 2021). In addition to the aforementioned heat-related ailments, workers may also face the risk of burns when exposed to hot surfaces, steam or fire during their tasks (NIOSH, 2016). These burns can range from mild to severe, depending on the intensity and duration of the exposure.

Excessive heat exposure also has demonstrated adverse effects on cognitive function, mental health and overall wellbeing. Prolonged exposure to elevated temperatures has been associated with physical discomfort and sleep disturbances, contributing to heightened stress and anxiety levels (Rony & Alamgir, 2023), as well as changes in mood and cognitive impairment (Piil et al., 2018). Further, higher temperatures have been linked to increased hospital admissions or attendance for mental-health-related visits (Nori-Sarma, Sun, & Sun, 2022; Thompson et al., 2023), as well as increased cases of suicide or suicidal behavior (Thompson et al., 2018; Thompson et al., 2023).

Finally, heat stress can also negatively impact overall worker productivity (Flouris et al., 2018; Morrissey et al., 2021; Zander et al., 2015). In cases of extreme temperatures, employers are advised to limit physical exertion, offer extended breaks or limit work hours to reduce hours of exposure. According to a meta-analytic study encompassing over 447 million workers, 30% of employees working in heat-stress conditions experienced losses in productivity, with these losses increasing an average of 2-6% for each degree above 75°F (22.9°C) (Flouris et al., 2018). The International Labour Organization estimates that by 2030, an estimated 2.2% of total working hours will be lost to high temperatures, a productivity loss equivalent to 80 million full-time jobs, and an economic loss of an estimated $2.4 trillion worldwide (Kjellstrom et al., 2019).

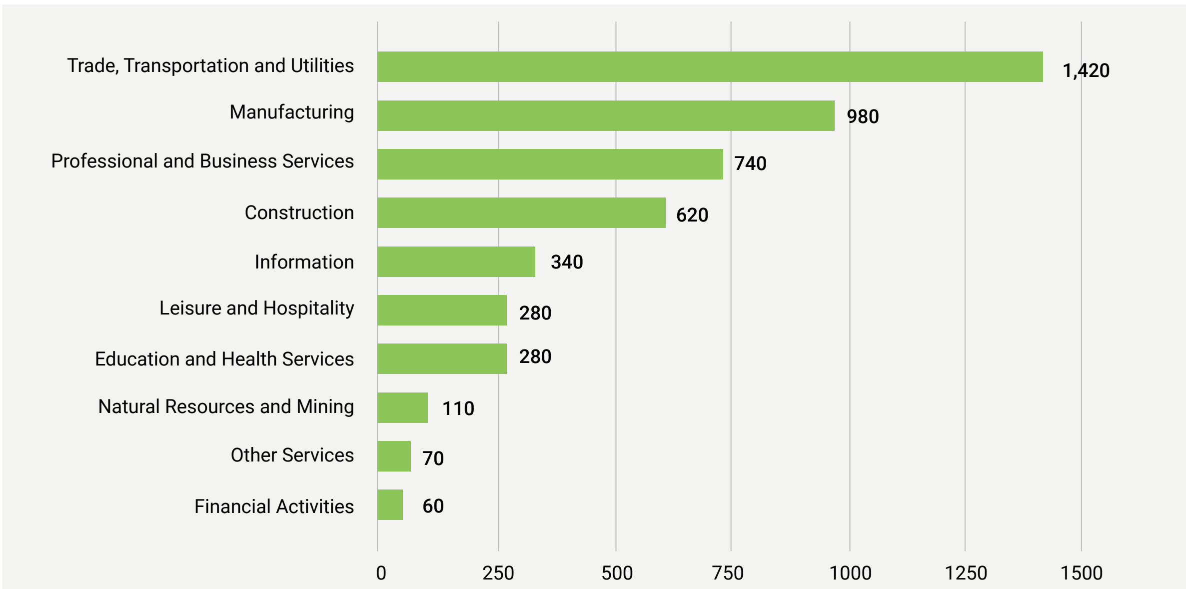
Who is at Risk?

In most industries, occupational heat stress originates from harsh environmental conditions, the requirement to wear insulated or impermeable protective clothing or performing physically demanding tasks (Arbury et al., 2014). A meta-analysis comprised of 111 studies found that working in temperatures of 77°F (25°C) increased the likelihood of heat strain for most occupations. Notably, this temperature drops to 71.6°F (22°C) when performing intense or strenuous activity (Flouris et al., 2018). The National Oceanic and Atmospheric Administration provides additional guidance on the likelihood of heat disorders based on outside temperature and humidity levels, with four risk classifications: caution, extreme caution, danger and extreme danger (NOAA, 2023).

For additional guidance, the NIOSH-OSHA Heat Safety Tool App is a useful resource for planning outdoor work activities, along with tailored occupational safety and health recommendations (NIOSH, 2022b).

In 2022, OSHA identified a list of 70 industries likely to have heat-related hazards. While working outdoors is a strong predictor of heat stress, indoor workers are not immune to heat-related SIF risks (see Table 1). Analysis of 66 heat-related illness investigations between 2011 and 2016 revealed that 80% of heat-related fatalities occurred in outdoor work environments. However, 61% of non-fatal illnesses cases occurred either during or after work originated from an indoor work environment (Tustin et al., 2018). Therefore, it is critical to consider other factors, such as working near hot equipment, lack of air movement and the physical demands of the tasks being performed.

Table 1. Number of Workplace Injuries Requiring at Least One Day Away from Work Resulting from Exposure to Environmental Heat, 2021-22 (BLS, 2023a)



The level of heat strain experienced can also vary based on several individual factors. One of the most important factors to consider is whether workers are acclimatized to the heat. Heat acclimatization refers to the gradual build-up of heat tolerance that comes from gradually increasing the intensity or duration of work performed in a hot setting. (NIOSH, 2016). According to an analysis of OSHA citations issued between 2012 and 2013, in cases of heat-related illness or death, acclimatization was the most commonly missing program element (Arbury et al., 2014). Notably, while this process is a recommended starting point for addressing heat stress risks, the level of protection it provides is variable and the body's ability to adapt to extreme heat is limited (Hanna and Tait, 2015). Therefore, acclimatization should not substitute other controls and a holistic approach to heat management. Other individual risk factors for heat strain include:

- Age, including both adolescents and older adults
- Clothing, including heavy, insulated and impermeable clothing or PPE
- Body Mass Index (BMI) > 30
- Hydration status
- Pregnancy
- Alcohol consumption
- Substance use, including diuretics, antihistamines and amphetamines
- Lower levels of physical fitness
- Comorbid medical conditions, such as diabetes, heart disease or high blood pressure (Leiva & Church, 2023)

Regardless of individual risk factors, NIOSH (2016) recommends instituting a medical monitoring program for all workers exposed to heat stress above the Recommended Alert Levels. This program is essential for assessing workers' health and physical wellbeing both prior to and while working in hot environments, providing necessary emergency care or treatment, and gathering the necessary medical information to identify work areas, tasks and processes that require additional prevention efforts.

Regulations

OSHA does not currently have explicit, industry-wide standards for heat stress mitigation. However, the General Duty Clause (Section 5(a)) outlined in the OSHA Act of 1970 (H.R. 1195) requires employers to provide a workplace free from recognized hazards that cause, or are likely to cause, death or serious harm, including heat-related hazards. In 2023, OSHA issued a heat hazard alert and announced that it would be intensifying its enforcement and increasing inspections in high-risk industries, including construction and agriculture (U.S. Department of Labor, 2023). Five states have also adopted standards not addressed by federal OSHA standards:

- **California:** California's *Heat Illness Prevent Standard* requires employers to provide adequate training, water, shade and planning when the temperature rises to 80°F or above (8 CCR §3395)
- **Colorado:** Colorado's *Agricultural Labor Conditions Rules* sets regulations to protect agricultural workers from heat illness and injuries, including standards for shade, increased risk conditions, as well as monitoring and response protocols (7 CCR §1103-15)
- **Minnesota:** Minnesota's *Indoor Ventilation and Temperature in Places of Employment* mandates that indoor workplaces must have sufficient airflow and maintain specific temperature conditions for employee safety (Minnesota Department of Labor and Industry, 2008)
- **Oregon:** Oregon's *General Occupational Safety and Health* provides regulations for industries, including construction, agriculture and forestry, that require engineering and administrative controls for work in high-heat environments and requirements for specific rest break schedules (Oregon Department of Consumer and Business Services, 2022)
- **Washington:** Washington's *Outdoor Heat Exposure* also provides regulations for shade, high heat procedures, training and responding to heat illness for outdoor workers (Washington Division of Occupational Safety and Health, 2023)

Heat Stress Mitigation Strategies

In situations where elimination and substitution are not feasible, several administrative and engineering controls are recommended to mitigate the adverse effects of extreme heat on workers. Foremost among these is the utilization of onsite Wet Bulb Globe Temperature (WBGT) meters. Recognized as the most accurate measure of environmental temperature's impact on the body (Morris et al., 2019), WBGT takes into account temperature, humidity levels, sun exposure and air movement. It is essential to monitor WBGT levels continuously and take appropriate action. Along with the standards noted above, there are also several voluntary standards organizations can follow, such as the American Conference of Governmental Industrial Hygienist (ACGIH) Threshold Limit Values, NIOSH Recommended Action Limit or Recommended Exposure Limit (Fontaine, 2022), or the American Society of Safety Professionals' voluntary standard for heat stress in construction (ASSP, 2024).

Training should be considered another vital aspect of any heat-mitigation program. Workers and supervisors should be trained in identifying, preventing and responding to heat-related illnesses before they begin work in a hot environment and before heat index levels increase (NIOSH, 2016). One study evaluated the impacts of a voluntary Heat Stress Awareness Program on heat-related illness among 604 municipal outdoor workers from 2009 to 2017. It found that training significantly reduced heat-related illnesses and a reduced median workers' compensation cost by 50% after the program was put into place (McCarthy, Shofer, & Green-McKenzie, 2019). According to NIOSH (2016), heat stress training programs should include the following:

- Recognition of the signs and symptoms of heat-related illnesses
- The causes of heat-related illnesses, as well as risk-mitigation practices
- Recognition of the signs and symptoms of heat-related illnesses
- The proper use of heat-protective clothing and equipment, as well as the potential added heat load stemming from clothing and PPE
- The effects of individual factors on heat tolerance, including acclimatization
- Reporting and response procedures for heat-related hazards or SIF events (NIOSH, 2016)

Another important consideration is whether workers are acclimatized to the heat. For those who are not acclimatized to hot conditions, NIOSH recommends a gradual increase in work time over a period of 7 to 14 days. After one month away from work in the heat, most worker's heat tolerance will have returned to baseline, warranting an additional period of acclimatization before resuming the normal workload (NIOSH, 2017a). Other interventions, including water, rest and shade at work, should be promoted to ensure workers have adequate time and resources available to regulate heat stress.

NIOSH (2017b) provides sample work/rest schedules to balance periods of work and rest, taking into accounting both the temperature and intensity of the work being performed (i.e., light, medium and heavy work).

Table 2. Controls for Minimizing Heat Stress Risks (Adapted from NIOSH, 2016)

<table>
<tr><th>Engineering</th><th>Administrative</th></tr>
<tr><td>• Use of fans, air conditioning, or ventilation systems on the worksite and/or in designated break areas
• Use of reflective or heat-absorbing shields or barriers
• Reduce steam leaks, wet floors or humidity</td><td rowspan="3">• Limit time in the heat and provide frequent breaks and recovery time in a cool area
• Reduce the physical demands of the job by implementing tools to reduce manual strain or increasing the number of workers per task
• Schedule activities for times when the heat index is lowest (i.e., early morning, late afternoon, evenings)
• Train supervisors and workers about recognizing and mitigating heat stress
• Use a buddy system where workers observe each other for signs of heat-related injury
• Provide cool, potable water and encourage workers to drink often
• Institute a heat alert program during periods of excessive heat or drought
• Institute a heat acclimatization plan</td></tr>
<tr><th>Personal Protective Equipment (PPE)</th></tr>
<tr><td>• Adopt heat-reducing PPE, such as cooling vests, moisture-wicking clothing, ventilated helmets, cooling rags and lightweight, loose-fitting clothing
• Adoption of technologies for heat stress mitigation, including vital signs monitoring wearables or personal cooling systems</td></tr>
</table>

Vital Signs Monitoring for Heat Stress Mitigation

In addition to the controls mentioned above, there are also technologies on the market which can help prevent or mitigate heat-related SIFs in the workplace, with one such example being vital signs monitoring wearables. Referring to sensor-equipped devices which monitor the physiological metrics of the individual wearing them (Idris & Pennington, 2023), these devices have garnered popularity in the mainstream market via devices such as the Apple Watch, Fitbit and Garmin fitness trackers.

While core body temperature is considered the most significant predictor of heat-related illnesses and injuries, direct measurements such as rectal thermometers or ingestible thermometer pills face significant challenges concerning invasiveness and ethics (Pizzani, Cauda, Morrissey, & Mills, 2023). As an alternative, wearables provide a noninvasive and portable means of monitoring the body's physiological responses to heat (Notley, Flouris, & Kenny. 2018). Some devices, such as in-ear sensors, can indirectly measure an individual's core body temperature, while others use proxy measurements, algorithms and data about the surrounding environment to make predictions and provide insight into the body's response to heat exposure (see Table 3).

Table 3. Proxy Vital Signs Measurements for Heat Stress (Adapted from NIOSH, 2016)

Core Body Temperature (CBT)	CBT is the most accurate means of measuring temperature. Under heat strain, CBT rises as the body's cooling mechanisms struggle to transfer excess heat efficiently.
Heart Rate	Heat exposure results in heightened blood flow to the skin, causing the heart to work harder and increasing beats per minute. Heart rate will remain elevated in a worker experiencing a heat-related illness.
Temperature	Increases in skin temperature may indicate a failure of the body's cooling mechanisms, contributing to risk of heat-related illnesses.
Blood Pressure	Blood pressure typically increases during periods of heat exposure. When a worker is suffering heat-related illness, blood pressure levels will not recover as quickly and may indicate medical attention is necessary.
Respiratory Rate	Heat stress can contribute to increases in breathing rates. When a worker is experiencing heat illness, these levels don't return to baseline as quickly as normal.
Fluid Loss	Sweating is one mechanism the body uses to transfer heat from the body. Excessive levels of sweat or fluid loss may indicate a worker is at increased risk for dehydration and other heat-related illnesses.

Vital signs monitoring wearables can be deployed through various wearable forms, each offering unique monitoring capabilities. Common deployment options include bracelets or smart watches (Idris & Pennington, 2023), smart helmets (Sharma, Suri, & Kant, 2022), smart clothing, such as gloves or vests (Idris & Pennington, 2023), upper-arm sensors (Ibrahim et al., 2023; Callihan et al., 2023) or in-ear sensors (EPRI, 2018; Sharma, Suri, & Kant, 2022). When deciding which deployment option is best for the organization, employers should consider several factors to ensure the technology meets their needs:

- **The nature of the work and environment.** Assess the work environment (e.g., outdoor vs. indoor, heat index, physical demands) to determine which wearable is best suited for workers. Prioritize devices that are comfortable for all-day wear and those that do not interfere with job tasks. If applicable, look for technologies which are certified for use in industrial settings and include capabilities such as water or dust resistance (Notley, Flouris, & Kenny, 2018). In some cases, Intrinsic Safety or ATEX may need to be considered as well for the use of electronic devices in or around explosive atmospheres.
- **Type of data needed.** Determine which vital signs and environmental variables need to be monitored (e.g., heart rate, temperature, hydration levels) based on the risks identified in the workplace. Also consider the level of data granularity and frequency required for effective monitoring and intervention.
- **Cost and return on investment.** Evaluate the upfront costs of the technology, considering hardware costs, ongoing subscription or service fees, and any additional expenses. For smaller companies, the focus should be on the co-benefits and cost-effectiveness of adopting new technologies, where additional capabilities may only be added on an as-needed basis (Pennington & Kapadia, 2021).

Market Overview

According to research and advisory organization Verdantix, vital signs monitors are considered to be in the "launch" phase of maturity, but increased adoption by organizations looking to connect workers through technology puts it on the cusp of "growth" (Idris & Pennington, 2023). As of 2020, the market for vital signs monitoring wearables for workplace safety was an estimated $70 million worldwide, with this figure expected to grow to $4.3 billion by 2039, a compound annual growth rate (CAGR) of 13.1% (Olaleye & Blackwell, 2019). While the technology accounted for only about 16% of the overall market for connected worker devices, vital signs monitoring receives the third largest spend by corporate EHS managers among those technologies (Olaleye & Blackwell, 2019).

For employers interested in exploring safety technologies, the Techhub Marketplace is a searchable directory of NSC-approved technology vendors. Users can sort by technology type, hazard, format or industry. Learn more at: nsc.org/techhub

Benefits of Vital Signs Monitoring

Vital signs wearables can offer numerous benefits for mitigating heat stress across various settings and industries. The integration of data analytics and machine learning algorithms allow for the identification of patterns, anomalies and early warning signs as a proactive approach to heat stress mitigation (Callihan et al., 2023). Oftentimes, these devices also account for differences between workers (e.g., age, fitness or medical conditions), allowing for a more individualized approach to heat stress monitoring.

Research on the effectiveness and accuracy of wearable technologies varies depending on the type of technology and the movement type being examined. However, several studies have validated the use of the technology for continuous health monitoring (Dunn et al., 2021), predicting core body temperature (Gaura, Kemp, & Brusey, 2013) and monitoring heat stress in high temperatures (Ibrahim et al., 2023). For a full list of studies conducted on wearables, including their associated industries and the physiological variables being measured, see Bustos et al. (2021).

Through the collection of physiological metrics, wearables can provide automatic data visualization or interpretation, warning signals or even direct instructions for the user to rest in response to heat strain (Pizzani, Cauda, Morrissey, & Mills, 2023), offering the potential to provide individualized and real-time notification of excessive heat strain (EPRI, 2018). A primary advantage of physiological monitoring is that it measures an individual's responses to heat exposure, rather than extrapolating from environmental conditions and estimated workload (NIOSH, 2016). These systems can alert if workers exceed permissible limits of heat strain (Sharma, Suri, & Kant, 2022), experience symptoms of heat strain or injury (Callihan et al., 2023) or are at an elevated risk for heat stroke (Son, Ramli, & Aziz, 2021). In sum, the use of wearable vital signs monitors has the potential to foster a healthier workforce, reduce absenteeism due to health-related conditions and improve workers' overall quality of life (Callihan et al., 2023).

These tools can also be a valuable educational tool for employees. For example, workers can observe patterns in their physiological responses to heat stress or physical exertion across different times and tasks, helping them better understand their body's own reactions and limits to heat exposure. These devices can also function as a biofeedback mechanism and draw connections between lifestyle choices and their occupational health and performance. For instance, users can see firsthand how lifestyle variables such as adequate hydration, sufficient sleep and their overall physical fitness influences their body's ability to cope with heat and stress. Such observations have the potential to motivate individuals to adopt healthier habits, both in their personal lives and at work, to mitigate the impact of heat stress and improve overall wellbeing.

Employers can also benefit from the adoption of vital signs monitoring technologies in the workplace. While traditional methods lack real-time monitoring and cannot provide immediate intervention or early warning signs for potential health issues (Callihan et al., 2023), the data collected by wearables can provide employers greater insights into their own workplace risks. For example, by aggregating data across the workforce, employers have the opportunity to better understand which occupations, locations or tasks face an increased risk of heat-related illnesses or injuries. These insights allow employers to redesign work practices or implement controls (Callihan et al., 2023), such as offering workers more breaks, instituting a heat acclimatization plan, or offering other cooling tools such as PPE, fans or cooling vests. Ultimately, the ability to proactively address and control for heat-related hazards can provide valuable data to track precursors to heat injuries or illnesses, ultimately contributing to reductions in workers' compensation insurance costs, increased plant efficiency and improved employee productivity (Idris & Pennington, 2023).

Barriers and Considerations

As with all technologies, the adoption of vital signs wearables faces several notable, yet navigable, challenges toward widespread adoption. First and foremost, these technologies rely on indirect, proxy measurements of heat stress (e.g., heart rate or skin temperature). While collection of key indicators, such as heart rate and skin temperature, can provide valuable information about the body's physiological responses to heat exposure, use of indirect measurements may potentially lead to misinterpretation of the body's risk levels. For example, heart rate may be impacted by a number of factors, such as certain medications, medical conditions or physical fitness (NIOSH, 2016). Thus, while use of the technology can estimate the body's response to heat exposure, wearables should be combined with additional heat mitigation strategies, including acclimatization procedures, work/rest schedules and training to ensure a more holistic risk management program.

In addition, vital signs monitors are still considered to be early within their maturity for EHS applications (Idris & Pennington, 2023). More research is needed to validate the use of wearable technology for applications within health and safety, as well as within dynamic environments (Dolson et al., 2022) and harsh industrial settings (EPRI, 2018). Further, the ability to effectively use digital technologies may be limited for some industries due to limited connectivity and a lack of the technological infrastructure necessary for deployment. Limited use cases and examples of successes with technology also represent another barrier to the adoption of technology (Work to Zero, 2020). The ongoing evaluation of wearables, particularly within health and safety contexts, as well as efforts to collect and disseminate successful case studies and best practices is crucial for overcoming these barriers and encouraging broader use.

Costs and resource investments also represent another key barrier toward the use of vital signs monitoring in the workplace. In general, costs will vary based on deployment methods, software complexity and functionalities. Nonetheless, up-front hardware costs, software subscriptions, and repair and maintenance costs remain a significant barrier toward adoption (Idris & Pennington, 2023; EPRI, 2018; Notley, Flouris, & Kenny, 2018; Svertoka, Rusu-Casandra, & Marghescu, 2020). Employers interested in piloting or implementing new technologies can leverage several strategies to reduce the initial costs of innovation:

- **Identify funding opportunities.** Grants and other funding opportunities may be available to support employers, especially small to medium-sized organizations, offsetting the initial expenses associated with piloting new technologies. These opportunities are commonly offered by government agencies, industry associations, research institutions or nonprofits.
- **Begin with small-scale pilots.** Launching a pilot project can be an effective way to learn, make corrections on a small scale and reduce investment risk. This process should include ensuring the technology is compatible with the organization's existing infrastructure, identifying "digital champions" within the organization to drive the pilot internally, engaging with end users and continuously assessing of the impact of the technology on KPIs (Work to Zero, 2022).
- **Identify highest-risk workers.** The initial investment into vital signs monitoring technologies can also be reduced by monitoring workers only during high-risk work or weather conditions (Notley, Flouris, & Kenny, 2018). Additionally, consider administering wearables only to workers performing physically demanding work or those who are more vulnerable to heat-related illnesses or injuries (EPRI, 2018; Notley, Flouris, & Kenny, 2018).

When considering new technology, employers should also contemplate the potential impact of the technology on the workforce. One potential barrier associated with wearables is ergonomic concerns (Idris & Pennington, 2023). Depending on the deployment option (i.e., wearable accessories, clothing or implantable devices), certain technologies may aggravate allergies or cause irritation throughout longer shifts (Idris & Pennington, 2023), or be uncomfortable for long periods of work (Saidi & Gauvin, 2023). These issues can potentially be avoided by having pilot participants trial new technologies and provide feedback via interviews or surveys to better understand these concerns. Furthermore, consider deployment options best suited for the specific industry and associated workflow necessary, prioritizing devices that are comfortable for all-day wear and those that do not interfere with job tasks.

Finally, workers may be reluctant to adopt vital signs monitors within the workplace. This reluctance may stem from several factors, including the belief that heat strain is not a significant hazard or that the data will be used to assess productivity, rather than safety (Notley, Flouris, & Kenny, 2018). Workers may be concerned their employer is potentially tracking productivity, comparing worker performance or gaining access to potentially sensitive data, such as health or performance metrics (Notley, Flouris, & Kenny, 2018).

Furthermore, because wearable devices most often communicate with other devices, they may be subject to a range of cyber-attacks. To combat this, wearable devices require higher security regarding encryption, data integrity, confidentiality and other security services (Ching & Sing, 2016). Employers should consult with the selected vendor to ensure these security protocols meet both industry standards and the organization's specific security requirements. While more research is needed to improve device security, several strategies can be leveraged toward the ethical use and compliance of sensitive health information:

- Engage with vendors to understand what data is being collected, how it is stored and protected, and how it is reported. Consider providing workers with a "digital consent form" with these details, including how the data will be used in the workplace.
- Evaluate whether the data can be aggregated or de-identified, meaning supervisors or managers cannot discern individual workers' specific health and safety data. This approach ensures individual workers' specific health and safety information remains confidential, while still providing valuable insights at a group level.
- Identify and engage early with key stakeholders, such as Legal, HR and IT. During initial conversations, this allows relevant stakeholders to ask questions, identify potential barriers and identify the supporting elements necessary to successfully adopt new technologies in the workplace.
- One of the most important steps during the pilot and implementation process involves engaging with workers and identifying a group of "digital champions" representing all levels of the organization (Work to Zero, 2022). These are individuals who possess a strong understanding of the technology being implemented and are proactive in learning about its benefits and potential applications within the workplace. Digital champions can ultimately facilitate adoption and effective use of the technology, educate and train peers on its use, and provide valuable insights and support across all levels of the organization.
- Regulations such as the EU's General Data Protection Regulation (GDPR) and the California Consumer Privacy Act (CCPA) have introduced new considerations for employers when managing worker data from all sources. Employers should be familiar with these, and other, regulations to ensure compliance and ethical use of data.
- Another challenge for employers is processing and analyzing large amounts of data (Svertoka, Rusu-Casandra, & Marghescu, 2020) and interpreting the physiological data being collected (EPRI, 2018). Modern devices commonly include a proprietary algorithm that may obscure the translation between input signal and reported values (Pizzani, Cauda, Morrissey, & Mills, 2023). It's crucial for employers to collaborate directly with technology providers to guarantee the data collected is being analyzed and utilized correctly.

Ultimately, vital signs monitors provide valuable insights for both workers and employers and can be an effective means for mitigating the risk of heat injury or illness in the workplace. However, this technology does not eliminate or substitute the need for workers to be exposed to hot environments. Therefore, these technologies should be combined with other controls to ensure a holistic approach to hazard recognition and control. This includes educating workers on identifying and responding to incidents of heat-related illness and injury, including awareness of the potential impacts of heat on physical and psychological wellbeing.

Case Studies

The following case studies are based on interviews conducted with representatives from organizations using or piloting safety technology The inclusion of case studies featuring specific vendors or technologies in this paper is purely for educational purposes and does not constitute an endorsement of any particular technology or vendor. Rather, the intention is to provide practical insights into the implementation and applications of vital signs monitoring technologies. These and additional case studies can be found at: nsc.org/wtzresources

1. Fratco's Use of the MākuSafe System for Heat Stress Mitigation

At Fratco, extruders are used to melt and shape clay, plastics and other materials during the manufacturing process of drainage pipe and other related products. These machines are extremely hot (400-500°F), contributing to the ambient heat inside the facilities. Furthermore, during the summer, outside air temperatures often reach daytime highs of 90°F, offering workers little reprieve from the extreme heat.

Supported by a financial grant, the company began piloting the MākuSafe system, which combines wearable technology with data analytics to provide real-time and predictive EHS data from worker strain and exertion, as well as environmental conditions such as extreme heat and humidity. Fratco has used this data to identify the jobs and areas at highest risk for heat stress, and ensure appropriate accommodations are being made for employees, such as providing cooling rags, additional breaks, fans and water breaks. As a result, they have seen a consistent reduction in the number and severity of alerts generated.

2. Perrigo's Use of SlateSafety Wearables for Heat Stress Mitigation

Perrigo, a leading manufacturer of pharmaceuticals and consumer products, uses large tower dryers during its production of powdered infant formula. Exposure to these tower dryers, along with elevated ambient temperatures in the manufacturing environment, significantly increases the risk of heat-related illnesses and injuries for workers.

To bolster their existing heat stress program, Perrigo adopted the SlateSafety Band V1, later upgraded to V2, an arm-worn device that monitors physiological indicators of heat stress such as exertion, heart rate and core body temperature. This technology has proved invaluable in mitigating heat stress. Real-time monitoring alerts both workers and supervisors when heat exposure thresholds are exceeded, prompting necessary safety measures such as rehydrating, taking breaks or adjusting work/rest cycles.

Furthermore, by identifying "hot spots" within their facilities, Perrigo has instituted several strategies to reduce worker heat exposure, including the institution of dedicated cooling areas, cooling garments, spot cooling practices and revisions to work/rest cycles for high-risk jobs. In the three years since adoption of the technology, Perrigo has had zero reported incidents of heat illnesses and injuries at the trial sites.

Conclusions and Future Direction

Any worker across various industries or occupations can experience heat stress. Working outside, near hot equipment or machinery, and physical exertion can all contribute to the risk of heat illnesses and injuries in the workplace. Through the monitoring of workers' physiological responses, vital signs wearables have the potential to identify and alert to potential signs or symptoms of heat strain, including cardiovascular activity, core body temperature and fluid loss. For employees, these devices can provide them with immediate and informed actions to reduce their exposure to the heat and prevent further illness or injury. For employers, these data can be used to inform their own workplace heat-mitigation strategies.

While use of vital signs monitoring has shown promise for monitoring heat stress in high temperatures (Ibrahim et al., 2023) and assessing physiological metrics in working environments (Bustos et al., 2021), more research is needed to validate its use within dynamic environments (Dolson et al., 2022) and harsh industrial settings (EPRI, 2018). The ongoing sharing of use cases and case studies is recommended to demonstrate the benefits, limitations and considerations for adopting wearables in the workplace. Finally, it is recommended that the ethical use of technology in the workplace, particularly regarding the collection and use of personal data, is an ongoing conversation between employers, workers, labor unions and industry leaders to promote transparency, safeguard worker privacy rights and foster a culture based on trust and accountability.

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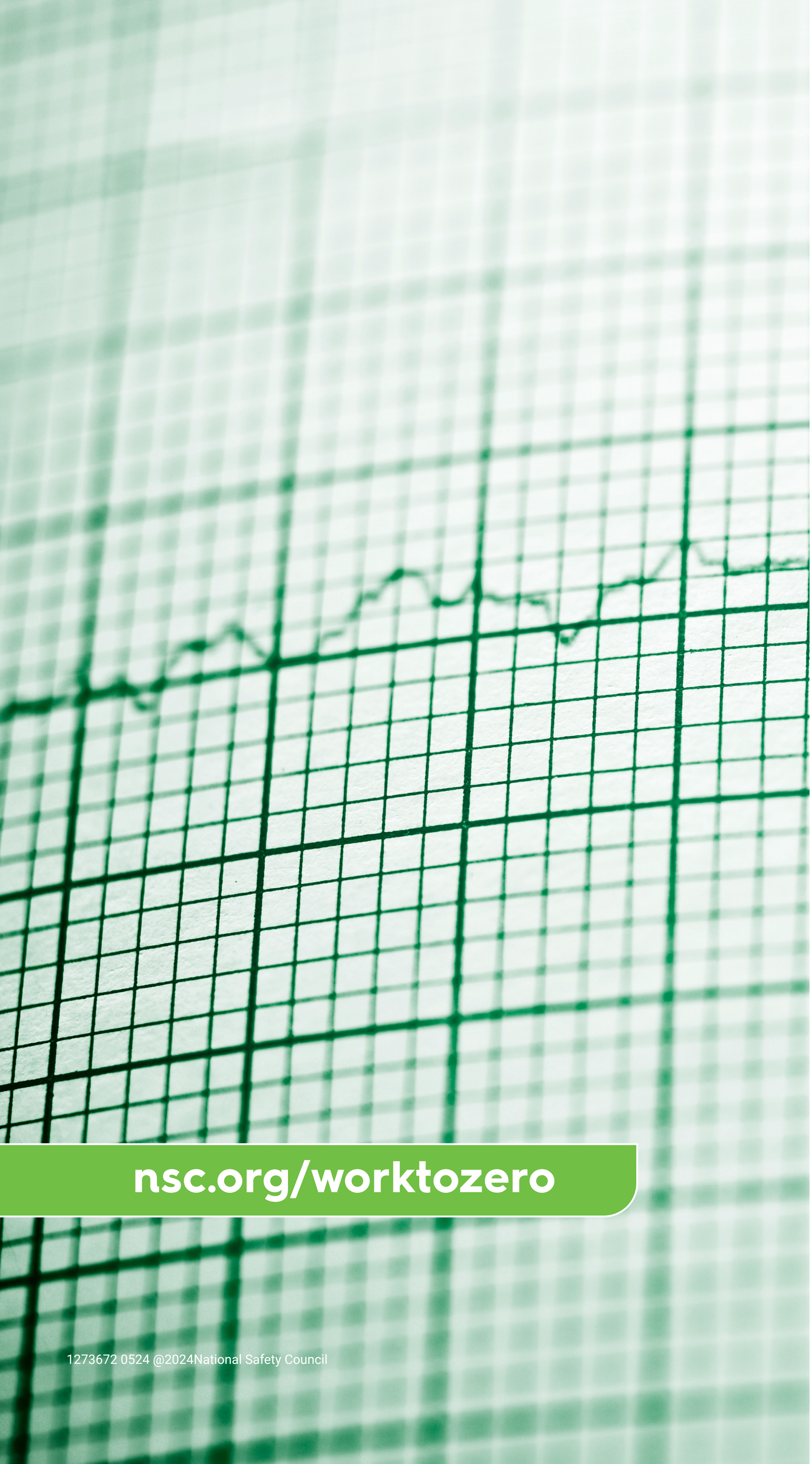

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