# Sensors and Gizmos and Data, Oh My: Informating Firefighters' Personal Protective Equipment


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## ABSTRACT

This study identifies communication design challenges associated with firefighters' personal protective equipment (PPE), an assemblage of wearable technologies that shield these workers from occupational hazards. Considering two components of modern firefighting PPE through Zuboff's (1998) theorization of information technology, we offer an extended case study that illustrates how these wearables, as interfaces, *automate* or *informate* firefighters' practice of safety. Often lauded for their abilities to augment firefighters' work capacities and increase safety outcomes, our analysis revealed that these wearables engender practices that expose firefighters to unforeseen hazards and displace the "tacit craft skills and knowledge" that these workers mobilize to mitigate workplace risk (Spinuzzi, 2005, p. 164). Drawing from these insights, we sketch four points of tension that communication designers, system architects, and practitioners may utilize to consider the informating potential of smart-firefighting PPE equipped with physiological sensors.



## Categories and Subject Descriptors

H5.3.Group and organization interfaces: Computer-supported cooperative work

## General Terms

Human Factors; Design

## Keywords

interface; occupational safety and health; wearables; PPE; automation




## PRACTITIONER TAKE AWAYS

- User interface design (UI), user experience design (UX), interaction design (IxD), and information architecture (IA) can be leveraged to improve the usefulness and ethical quality of personal protective equipment (PPE) used in occupational contexts.
- Automating and informating logics are instantiated within wearable PPE as interfaces and in the practices workers use to interact with environments while wearing these protective technologies.
- When introducing new PPE components to occupational settings, communication designers and system architects must account for the impact they will have on the existing practices workers utilize to create tacit knowledge about risk and safety.
- Communications designers must account for the distinct values and cultures surrounding the practice of occupational safety and health within organizations, which can impact whether and how end-users interact with wearable technologies.

## INTRODUCTION

Recently, scholars in professional and technical communication explored the methodological, theoretical, and ethical connections between the fields of communication design and rhetorics of medicine and health. Extending Scott, Segal, and Keranen's (2013) call for "work with other scholars/researchers inside and outside of disciplinary rhetorical studies" (p. 1), Meloncon and Frost (2015) argued for "more active and critical engagement in both the practice (our teams and in authorship) and in scholarly orientation (reading across boundaries)" (p. 11). Collaborative communication design work in this area, Meloncon and Frost posited, might strive to enhance the quality and experience of patient care by improving the accessibility of medical and health information, increasing patient agency in patient-provider interactions, facilitating health literacy initiatives, advancing conversations about medical and bio-ethics, and investigating the influence of technologies and wearables.

Thereafter, Gouge and Jones (2016) urged scholars to interrogate what it means for technologies to “be connected to bodies” (p. 201). While Gouge and Jones placed distinct emphasis on the theoretical and methodological value of “broadening the definition of wearables and critically exploring a more diverse range of such devices” (p. 205), their special issue featured a number of articles that centered on medical wearables such as mHealth (Teston, 2016), breast pumps (Jack, 2016), and ostomy pouches (Kessler, 2016).

In this article, we respond to these calls by exploring how research in communication design and rhetorics of medicine and health might inform the design and practice of firefighters’ personal protective equipment (PPE), a class of wearable technologies that shield these workers from the hazards they encounter in occupational settings. This study grows from our ongoing work, as members of cross-institutional collaborative between scholars from Colorado State University and leaders from Poudre Fire Authority, to improve safety and health outcomes in firefighting through transdisciplinary participatory action research (e.g., Blythe, Grabill, Riley, 2008; Fals-Borda, 2001; Simmons, 2007; Spinuzzi, 2005). It connects directly to an exigency that we realized while working with designers from AvidCor on an National Science Foundation (NSF) funded project to adapt a physiological wearable prototype for use in the profession of firefighting. We sought to understand how introducing a physiological monitor, as a component of the larger ensemble of PPE that firefighters wear, might impact the “complex of artifacts, practices, and interactions” (Spinuzzi, 2005, p. 165) firefighters mobilize to safely work in hazardous environments. Identifying concrete examples of the types of communication challenges firefighters experience while wearing and interacting with PPE, we surmised, would enable our team to better consider how interface design (UI), interaction design (IxD), user experience design (UX) might inform our approach to redesigning the AvidCor prototype. Most notably, we hoped to interrogate how introducing a physiological wearable to the fire-service might “enabl[e] or, alternatively, den[y] [firefighters] access to participation…as a result of their relationships to wearing [PPE]” (Gouge & Jones, 2016, p. 205).

To address this exigency, we sketched out three aims for the current study: (a) to discover if/how issues of communication design had been treated within existing literature on firefighters’ physiological wearables, (b) to familiarize ourselves with the types of communication design challenges firefighters encounter while wearing existing forms of PPE, and (c) to envision communication design challenges that might impact how firefighters orient to the introduction of PPE equipped with physiological monitors by drawing from the practitioner and transdisciplinary knowledge our collaborative possesses.

Toward those aims, we begin by offering readers who may be unfamiliar with firefighting PPE a brief history of these wearable technologies, spotlighting the recent emergence of “smart firefighting technologies” (Grant, Hamins, Bryner, Jones & Koepke, 2015) such as wearables and real-time data analytics within the occupation. Next, we situate our work by describing how Zuboff’s

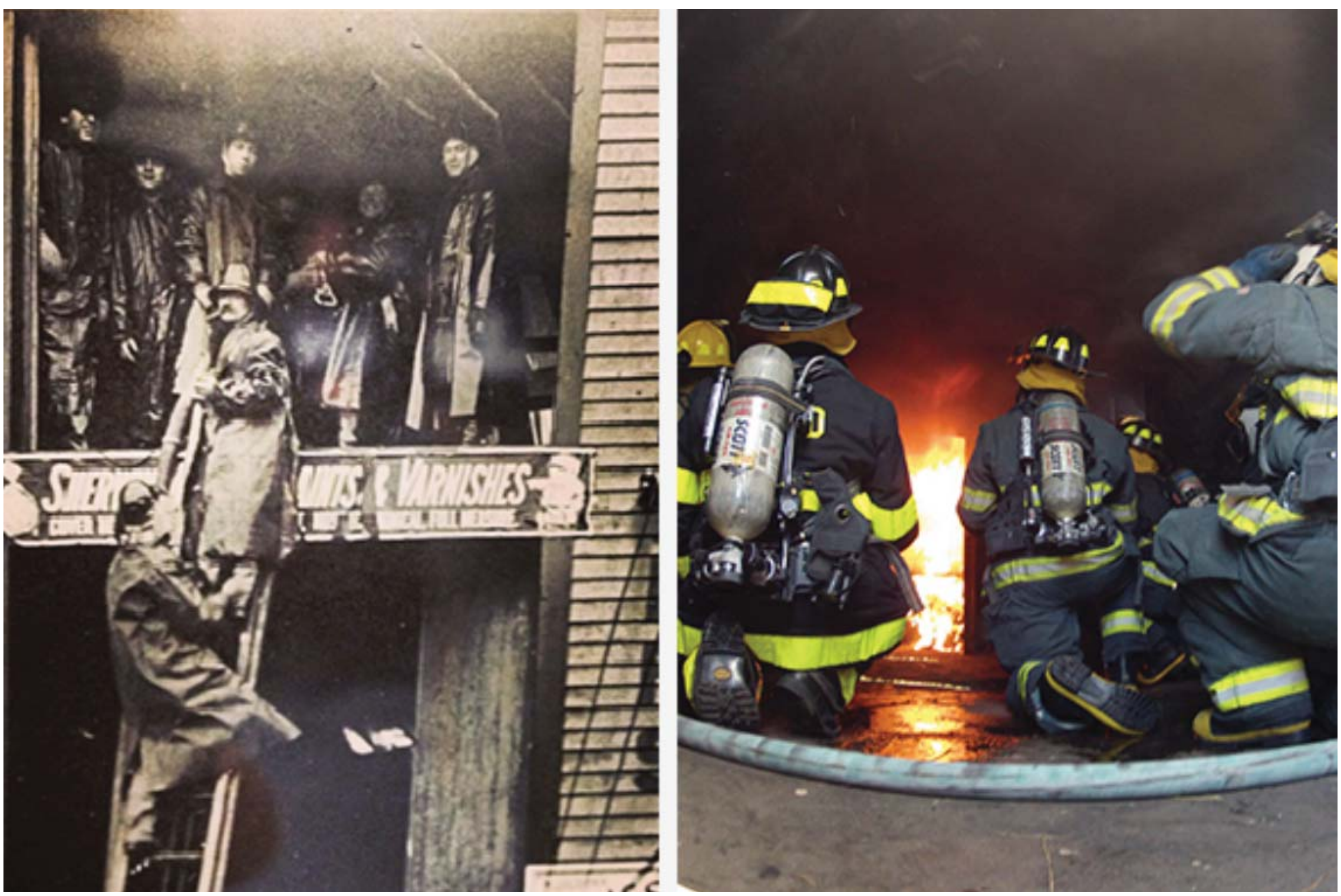

**Figure 1: Firefighting PPE has evolved overtime. Left: Firefighters wear rubber coats, aluminum helmets, and 3/4 length rubber boots; Right: Firefighters wear bunker gear made of advanced heat-resistant fabrics, fiberglass helmets, and SCBA.**

(1988) theory of information technology, especially the conceptual delineation she drew between *automating* and *informating* technologies, might enrich communication design in the field of rhetorics of health and medicine; introducing our cross-institutional, transdisciplinary research collaborative; and scanning the body of research encircling the design of firefighting' physiological monitoring devices. Thereafter, we describe the approach we used in this study, placing a particular emphasis on the methods and sources we used to assemble a case study of two components of modern firefighting PPE: (a) flash-hoods, which shield firefighters' necks, ears, and heads from burns, and (b) the passive end-of-service-time-indicator (ETOSI) alarms in self-contained breathing apparatus (SCBA), which signal that firefighters are working on reserve air. Reading the two components of PPE as worn interfaces, we call out examples of the ways these technologies automate and/or informate firefighters' practice of workplace safety (Zuboff, 1998). Our analysis reveals that PPE function as "reality-shifting media" (Pedersen, 2013, p. 2) that "enhance human capacities" (Hayles, 1999, as cited in Pedersen, 2013, pp. 15), and resonates with Kessler's (2015) finding that "[wearable] technology actually serves to constrain or control users in particular ways" (p. 238). PPE might increase protection from known hazards, but these interfaces can also displace the "tacit craft skills and knowledge" (Spinuzzi, 2005, p. 164) that firefighters mobilize to identify and respond to risk. Moreover, PPE can introduce new hazards or expose firefighters to unforeseen hazards because this equipment changes how they practice and enact work. We close by envisioning four points of tension that communication designers, system architects, and practitioners might use heuristically in the critical design of next-generation-smart-firefighting PPE. Each of these four-points, we hypothesize, will be sites of tension between *design paradigms that seek to automate* firefighters' work and *design paradigms that seek to informate* firefighters' work by increasing timely access to mission-critical information that could enrich and facilitate decision making.

## Automating and/or informating technologies

The use of wearable PPE in the fire service can be traced to the Sparteoli, a Roman firefighting force organized by Augustus (27 B.C.E), whose members wore protective hats, shirts, and shoes woven from the Esparto plant to protect themselves from burns while they attempted to suppress fires from outside of structures (Hirst, 1884). Over time, firefighters developed an assemblage of technologies to create PPE ensembles that improved the comfort and protective capabilities of earlier designs, enabling firefighters to enter structures and work confidently in closer proximity to hazards such as fire, falling debris, water, and smoke than they had in the past.

While PPE are primarily understood as wearable technologies that shield firefighters from occupational hazards, innovations in PPE have led to improved communication design and usability of these interfaces. For instance, after the first leather helmet designed specifically for firefighters was created in the 18th century, a luggage maker and volunteer firefighter in New York City later refined the design by adding channels and a duck-bill that channeled water away from firefighters' faces and toward their backs (Piatti & Frost Piatti, 2002; Hasenmeier, 2008). This redesign enhanced the UX and UI of the helmet because diverting water from firefighters' eyes engendered better visibility and improved comfort in work environments.

Still, improvements in comfort and protective capabilities have often come with a price: exposure to new or unforeseen occupational hazards. For example, when Scott Aviation invented the self-contained breathing apparatus (SCBA), a harness mounted air-pack that enabled firefighters to breathe compressed air through a mask, firefighters began to work closer to the seat of the fire. This component of PPE offered firefighters increased respiratory protection, but they quickly discovered that the protective coats and pants they wore did not provide sufficient thermal protection necessary for working closer to the seat of the fire. Consequently, this led the National Fire Protection Association (NFPA) to develop, *NFPA 1971 [19T-A]: Tentative Standard for Protective Clothing for Fire Fighters* (1973), the first standard which prescribed design parameters for how this class of wearable technologies should perform when exposed to "direct flames, sparks or embers, types of acids and gases" (p. 872).

Over time, both PPE technologies and the design standards outlined in NFPA 1971—a standard that has undergone nine revisions—have evolved in significant ways. Yet, the emergence of next-generation PPE, wearables equipped with physiological, geographic, and environmental sensors will present new challenges for firefighters and fire-service leaders, manufacturers, communication designers, and researchers alike. As Grant and colleagues (2015) argued in a recent report sponsored by the National Institute for Standards and Technology (NIST), these technologies "can revolutionize today's fire service, making firefighters more effective and efficient, positively influencing their safety and health" (p. 18). Integrating these designs within the fire-service will be a major undertaking because, as Grant et al. observe, they will require a "paradigm shift" from "tradition-based tactics" and "data-poor decision making" to "data-driven science-based tactics" and "information-rich decision making" (2015, p. 9).

**Table 1: Transformation from tradition-based firefighting to smart-firefighting (Grant et al., 2015)**

| Current State | Future State |
|---|---|
| Tradition-based tactics | Data-driven science-based tactics |
| Local information | Global information |
| Data-poor decision making | Information-rich decision making |
| Lack of awareness | Situational awareness |
| Untapped or unavailable data | Comprehensive data collection, analysis, and communication |
| Isolated equipment and building elements | Interconnected equipment and building monitoring, data, and control systems |
| Human operations | Human controlled, collaborative, and automated operations with inanimate objects (buildings, machines, etc.) |

While our own views on smart-firefighting align with Grant et al. (2015) in some ways—we share the idea that there are some striking tensions between existing and emergent designs and also argue that smart-technologies could positively influence firefighters' safety and health outcomes—we are concerned that the authors of the NIST report articulate a false binary by broadly painting the practices and tools firefighters currently use to construct and communicate information in a deficit rhetoric.

Such a stance is, perhaps, to be expected. As Swarts (2013) observed, "[t]hrough their designs, tools accumulate knowledge and perspectives that have situated value. . . . [T]ools reflect some values to the exclusion of others" (p. 152). Similarly, Spinuzzi (2005) warned that Taylorist approaches to management often deem the tools, practices, and processes through which tradespersons construct knowledge in "craft traditions" as "inferior" (p. 165). Building on earlier research in this area (Mirel, 1998; Muller, 1997;1999; Nardi and Engeström, 1999) but gesturing directly toward Zuboff (1988), Spinuzzi explained that "tacit knowledge often remains invisible: since it is not made systematic or quantifiable, it passes unnoticed and often undervalued" (p. 166). Indeed, Zuboff observed (1998) information technology (IT) had a profound impact within occupational organizations not only because it could be used to automate work by distributing labor previously performed by humans to computers, but also because automating labor with computer-mediated technologies created information that could be used by workers and managers to informate their activities (pp. 9-11). The "'textualization' of the work environment," as she framed it, brought with it new dilemmas (2015, p. 76). For instance, managers could use these data to surveil subordinates and control labor processes with greater precision, or these data could be delivered to workers who might develop "intellective skills" for learning about, relating to, and gaining mastery of their work in new ways (pp. 75-79). In sum, Zuboff posited that system architects and organizational leaders would have to confront choices within a design paradigm that ranged from positioning IT as automating technologies that would replace humans to informating technologies that would render previously concealed dimensions of production visible in turn presenting new challenges and opportunities for innovation (p. 11).

Although Zuboff's *In the Age of the Smart Machine* (1998) is nearly three-decades old, we contend that UX, IxD, and UI could gain much by revisiting this work. Zuboff's theory fundamentally affects the consequences and stakes associated with designs that influence how humans experience, interact, and interface with information and computer-mediated technologies. Most importantly, concepts that occupy more ancillary roles within Zuboff's broader theory, such as intellective mastery, workers' feelings of apprehension, workers' use of technology as defense, and managers' use of technology for enforcement, [1] can be useful for thinking through the possibilities and implications of introducing wearable technologies such as physiological monitoring to occupational settings.

## A cross-institutional, transdisciplinary research collaborative

Our interest in physiological wearables, as well as our transdisciplinary collaborative, grew from a shared concern for firefighters' occupational and safety outcomes. Practitioners affiliated with PFA and researchers at CSU had collaborated on communication design projects in the past such as assessing organizational learning following after action reviews (Williams & Callahan, 2016) and administering a firefighter health and fitness program that provides over 1,500 firefighters in Colorado access to comprehensive medical screening to detect cardiovascular disease along with a health/fitness literacy program that offers lifestyle behavior modification counseling (Donovan et al., 2009; Li, Lipsey, Leach, & Nelson, 2017). Through this work, we began to wonder how our unique institutional and disciplinary expertise, if combined, might allow us to design a novel approach toward understanding the ways physiological (e.g., sleep deprivation; fitness; cardiovascular performance) and human factors (e.g., communication; risk perception; decision making; workplace literacy practices) connect to firefighters' occupational and safety outcomes.

With support of seed funding from the Pre-Catalyst for Innovative Partnerships (PRECIP) program, a university sponsored initiative to facilitate the development transdisciplinary research teams, we began to coordinate our expertise. We applied for national grants to acquire the resources necessary to conduct a study of this nature and we organized a symposium that brought researchers and leaders from over 20 national fire-service organizations together to envision solutions to the grand challenges of work, learning, and safety in the profession (Amidon, Williams, Lipsey, Henry, & Callahan, 2016). Still, we had difficulty identifying an affordable method for reliably and safely measuring firefighters' physiological performance in realistic live-fire-training-evolutions. Following the symposium, a colleague introduced us to the designers of the AvidCor physiological monitor, and our collaborative made a decision to partner with them to help adapt an existing prototype for use in the fire-service.

While applying for grants, we conducted a more detailed environmental scan to see if a commercially available physiological monitoring device for firefighters already existed and to determine if researchers had used similar devices to collect data about and/or study firefighters' physiological, communicative, or operational performance. We discovered that a variety of researchers and manufacturers were developing PPE with physiological, environmental, and/or geographic sensors embedded, but it appeared that these studies had been conducted in clinical or simulated settings. Further, it appeared that researchers conducting this work were primarily concerned with overcoming technical barriers associated with engineering smart-firefighting PPE or integrating physiological monitors within firefighting PPE. More specifically, these studies fell into four general strands: (a) studies focused on identifying what types of sensors might capture physiological, geographic, and environmental data that might be meaningful to firefighters (e.g., Chang et al., 2015; Koohi et al., 2010); (b) studies that sought to determine the best locations and approaches for embedding physiological, geographic, and environmental sensors within firefighting PPE (e.g., Batalin et al., 2013; Bonfiglio et al., 2010); (c) studies concerned with overcoming challenges that would impact the functionality of devices when introduced into extreme environments where firefighters work (e.g., Alam & Hamida, 2014; Florea et al., 2013); and, (d) studies concentrated on refining methods for capturing reliable and accurate of physiological data (Dolezal, et al., 2014; Dolezal, et al., 2015). Our scan suggested that communication design issues such as privacy, access, data management, and information overload—which might strain firefighters' trust in these designs—had not been addressed in great detail within the body of literature.

**Table 2: Considering physiological wearables in firefighting through fields of communication design**

| Information architecture (IA) | User experience (UX) | Interaction design (IxD) | User interface design (UI) |
|---|---|---|---|
| What forms of physiological data (e.g., core body temperature; oxygen saturation; electrocardiogram) are most meanful to those fulfilling different roles in fire-service organizations? | How accessible will these wearables be to departments located in jurisdictions that cannot afford them?<br><br>What levels of privacy should firefighters expect or demand from devices that have the potential to track physiological performance?<br><br>How should fire service organizations handle the inadvertent discovery of health or medical conditions that could cause a firefighter to be disqualified from work?<br><br>What are the legal and ethical concerns surrounding whether fire departments, fire officers, and municipalities should collect fine-grained physiological data about an individual firefighters' cardiovascular health or fitness? | What forms of physiological data should firefighters of various ranks have access to and why?<br><br>How might introducing these streams of data impact firefighters' existing work practices?<br><br>When might firefighters' (e.g., privates assigned to engine companies or captains of truck companies) or members in fireservice organizations that perform administrative work (e.g., dispatchers; training officers) benefit from access to raw data?<br><br>When might firefighters fulfilling different roles benefit from data that had already been converted to information? | How might these data be provided to firefighters, officers, and incident managers, so as not to distract them from working in environments that are already saturated with raw data?<br><br>How might data or information displays be built into existing PPE components such as air masks, portable radios, or SCBA? |

Aware that communication design could enrich the ways researchers and engineers were approaching the integration of physiological monitors within firefighting PPE, we began asking how UX, IA, IxD, and UI might improve these designs (See Table 2). We were concerned that the scenarios manufacturers and researchers had envisioned to demonstrate the potential uses of data collected by these wearables seemed to consider (primarily) the needs of the incident commander, while attending only superficially to the ways these data might inform decision making for front line firefighters. For example, in Grant and colleagues' (2015) depiction of the "Smart Fire Fighting process" only an incident commander receives data from the sensors deployed at a fire (See Figure 2).

The visualization of the proposed design, in other words, seemed to work from the premise that front-line firefighters are not consumers of information that might enrich their decision making. That is, these envisioned designs integrate automating technologies to firefighters' practices, but may not fully appreciate how the power to informate firefighters' work could create new opportunities for firefighters to integrate these data and information within their occupation (Zuboff, 1988).

## METHODS

Our collaborative approaches research from an action research paradigm (e.g., Blythe, et. al, 2008; Spinuzzi, 2005). Action research "seeks to bring together action and reflection, theory and practice, in participation with others, in the pursuit of practical solutions to issues of pressing concern to people, and more generally the flourishing of individual persons and their communities" (Reason & Bradbury, 2001, p. 1). Brydon-Miller, Greenwood, and Maguire (2003) delineated three tenets of action research: (a) knowledge is constructed, (b) "all research is embedded within a system of values," and (c) this research "promotes some model of human interaction" (p. 11). Indeed, this project, and all of the research coming from our collaborative, recognizes the co-creation of knowledge that is specifically shaped by the values of both the academic community and the fire service and poses real implications for safety within the fire service. For this particular project, we adopted a case study approach to explore communication design issues associated with firefighting PPE. Using this approach is ''both a process of inquiry about the case and the product of that inquiry'' (Stake, 2005, p. 444). That is, the case study approach allowed us to analyze a phenomenon and identify which aspects of it mattered to our aims as we constructed a case from a variety of sources. Drawing on the practitioner experience within our collaborative, we identified flash-hoods and low-air alarms as two types of contemporary PPE that would exemplify how the introduction of new wearable technologies within the occupation presented unforeseen communication design challenges that have adversely impacted safety and health outcomes.

Next, we turned to collecting data about the adoption of these two types of PPE to construct our cases. The case-study approach relies on using a multitude of sources to locate themes. Specifically, we searched for examples where flash-hoods and low-air alarms had adversely impacted firefighters' safety and health within three corpuses that contain information on communication design issues: (a) after incident analyses of firefighter line of duty deaths published within the National Institute for Occupational Safety and Health's (NIOSH) Firefighter Fatality Investigation and Prevention Program database; (b) articles appearing in one prominent U.S. firefighting trade magazine, *Fire Engineering*; and (c) standards promulgated by the National Fire Protection Agency. We analyzed the corpus of documents surrounding these PPE components to identify examples of communication design challenges that coincided with firefighters' practice of wearing PPE. We contend


**Figure 2: Depiction of an incident manager as the end-user of data collected by cyber-physical sensors (Grant et al., 2015).**

that the case study reveals that designers of firefighting PPE may not fully appreciate the communication and information exigencies that firefighters and incident managers encounter while working in hazardous environments. Finally, we used this knowledge as a launching point for a series of focused conversations [2] about how the insights we gleaned might extend to the design and use of smart-firefighting technologies and physiological wearables.

## FIREFIGHTING PPE: CASE STUDIES OF PROTECTIVE FLASH HOODS AND LOW AIR ALARMS

### Protective Flash Hoods

Thirty years ago, firefighters began using protective flash hoods to shield their necks and ears from heat. While the use of protective hoods is nearly ubiquitous today, it was not until the 1991 revision of *NFPA 1971* that these wearables were recognized as an essential component of a firefighter's protective ensemble. Despite the widespread use of protective hoods in the fire-service, they are not universally accepted, as a number of U.S. fire departments neither issue protective hoods as a standard component of a firefighters' PPE nor require firefighters to wear this article of protective equipment while working. Recent investigations of fatalities in Boston (MA) Fire Department (NIOSH, 2016) and Hartford (CT) Fire Department (NIOSH, 2017) prompted OSHA (2015) and NIOSH (2016; 2017) to issue recommendations that these departments issue hoods and require their use in accordance with *NFPA 1971* (2013b), but only one of the two departments has formally acted on this recommendation because compliance with NFPA standards is voluntary (Besthoff, 2015).

Despite attempts by occupational safety and health organizations such as NFPA, NIOSH, and OSHA, which have sought to standardize


**Figure 3: A firefighter dons a protective flash hood (USN/Vazquez, 2014).**

the wearing of flash hoods, the usefulness of protective hoods continues to be a site of heated contention among firefighters.

One example of the intense friction about the relative value of protective hoods can be seen in the set of exchanges that followed *Fire Engineering*'s (2012a) decision to publish an image of Detroit (MI) firefighters preparing to enter a residential structure fire without protective flash hoods on the cover of the trade magazine. Thereafter, a number of readers wrote letters to the editor criticizing the selection:

> I am very disappointed in the May 2012 cover. We see several Detroit, Michigan, firefighters preparing an offensive attack on a working structure fire. If you look closely, several of the firefighters are in personal protective equipment (PPE) but they are not wearing any fire protective hoods—including a firefighter I assume to be an officer because he is wearing a red helmet. There is absolutely no excuse for that. […] Tom Francesconi, Chief, Cheshire (MA) Fire Department (Halton, 2012, p. 51)

> The fire service, with help from the National Fallen Firefighter Foundation and FirefighterCloseCalls.com, has really come a long way in improving the safety culture. […] To then find an image like this on the cover of one of the most respected training magazines is disheartening. It sends the wrong message to the entire community. I'd hate to have a firefighter look at that image and even subconsciously decide that it is OK to not wear a hood because the pros from Detroit don't. Chadwick Wachs, Firefighter/EMT, Castle Rock (CO) Fire & Rescue Department. (Halton, 2012, p. 51)

These letters revealed that some readers held strong positions about the safety protective hoods offer firefighters. The Editor-in-Chief of *Fire Engineering*, Bobby Halton, defended the decision to publish this cover image:

> We were fully aware that many firefighters assessing this photo would regard the lack of hoods as part of PPE as dangerous. We also assumed that firefighters would understand the greater meaning of the photo and would not assume that we were endorsing a lack of PPE as prudent or preferable. Further, as part of a training dialogue, we would expect company officers and those viewing the photos to discuss the lack of PPE and reinforce its importance to those with whom they are discussing the photo. The value of these discussions is immeasurable; this is where the real learning takes place. […] [T]he firefighters in the photo were wearing all of their PPE issued from the city of Detroit. Unfortunately, they were not issued hoods as a normal piece of their PPE ensemble. If a Detroit firefighter wishes to wear a hood, he must purchase it at his expense. […] We hope that in time the fortunes of that city will turn around and the city will be able to better equip its firefighters with the same standard PPE that most of the nation enjoys. (Halton, 2012, pp. 52-53)

Note that Halton defended the choice to publish the image by framing it as an opportunity to create "training dialogue" about the relationship of PPE to firefighter safety, while also carefully carving out a space that was sensitive to the Detroit Fire Department's jurisdictional authority to define which components of PPE were issued as standard. Moreover, Halton offered an economic argument to rationalize why firefighters were not wearing protective hoods, despite the fact that firefighters wore SCBA and turnout gear which can cost departments thousands of dollars in comparison to hoods, which retail for as low as $20 dollars.

Factors beyond economics are at play, and we maintain that one of those critical factors is trust: changes in technology are often met with scrutiny by firefighters because they learn to trust tools and practices that have kept them safe while working in the past. Hoods indisputably offer firefighters an increased level of thermal protection from heat (Johnstone, et al., 1995; Prezant, et al, 2001; Halton, 2013), but historical accounts demonstrate that firefighters entrusted their ears with signaling changes in work environments that indicated that it was too hot to continue working safely:

> Our ears are thin, and cold and heat affect them rapidly. Fire[fighters] used their ears to tell them when it was too hot (when the flesh on your ears starts to sting, it's time to exit or back away). A Nomex hood covering the earlobes dulls the sensation of heat. […] With his sense dulled, the firefighter relies on visual cues. (Hensler, 2011, p. 29)

> Our gear is too good; it gets us into places that we shouldn't get into, and that's the reason firefighters are getting hurt." A derivation of that theme is, "I don't think we should wear hoods because if it gets too hot, we can't feel the heat on our ears." (Halton, 2013, p. 6)

Introducing protective hoods—a new interface—within occupational settings fundamentally changed how firefighters interacted with their work environments. The heat-resistant material from which manufacturers crafted these hoods certainly increased the thermal protection of firefighters' PPE ensembles, but fabrics like Nomex also dampened firefighters' abilities to feel heat. That is, protective hoods displaced an embodied practice for sensing and interpreting risk that firefighters had entrusted with keeping them safe for hundreds of years. Consequently, this compelled some firefighters to resist these new wearables and others to develop new practices that relied on visual information to identify and manage their risk-profiles.

## Low Air Alarms

When working in environments that are immediately dangerous to life and health (IDLH), firefighters wear SCBA for respiratory protection. SCBAs not only allow firefighters to breathe in toxic environments, but also include an array of passive safety sensors that provide information about the device to firefighters. One specific system integrated within SCBA is the end of service time indicator, also known as a low-air alarm. These devices use audible and haptic vibrating alarms located in the SCBA regulator to signal that firefighters have begun consuming their reserve air and they should have already exited an IDLH environment. In practice, firefighters have interpreted the meaning of the low air alarm in a variety of competing ways.

Between the late 1990s and early 2000s, a series of injuries and fatalities associated with firefighters running out of air prompted the fire service to reflect on how firefighters were using SCBA. During a high-rise fire in Missouri, for example, a captain and firefighter were exiting an IDLH environment due to low air, but re-entered after hearing a radio report that a civilian was trapped. Both the captain and the firefighter ran out of air and became disoriented—

**Figure 4: A firefighter inserts a SCBA regulator into a face mask; According to *NFPA 1989* (2013c) the ETOSI (low-air alarms) located in the regulator must begin to vibrate and emit a sound when the air supply reaches 33% of cylinder capacity (USN/Price, 2016).**

the captain was found unresponsive later by another firefighter, nearly perishing in the event (NIOSH, 1999). In a separate event, two firefighters in a supermarket fire in Arizona were exiting an IDLH environment due to low air, but became disoriented. While one firefighter was rescued, sustaining injuries from smoke inhalation, the other perished (NIOSH, 2001). Similar events in Seattle (WA) Fire Department, caused Bernocco et al. (2003) to develop a program for training firefighters in the department to manage their air:

> None of us in the department had even been trained in the concept of air management. Yet, the [NIOSH] has recommended training in air management as a way to prevent future fatalities, and the [NFPA] 1404, Standard for Fire Service Respiratory Protection Training—2002, states that the time necessary for entry, work, and exit from a hostile environment should be considered for each firefighter, since it varies among individuals. (2003, p. 58).

Indeed, the first edition of *NFPA 1404: Standard for Fire Department Training and Use of Respiratory Protection Equipment* (1989) specified that fire departments should teach firefighters how to "identif[y] the factors which will affect the duration of air supply" and "determin[e] the point of no return for each firefighter" (p. 249). Yet, many jurisdictions had not developed formal training programs in air management, so Bernocco and three of his fellow Seattle firefighters, Gagliano, Phillips, and Jose, authored *Air Management for the Fire Service* (Gagliano et al., 2008). From a communication design perspective, this book was revolutionary because it not only extended a critical gaze to firefighters' use of SCBA, but also offered training officers concrete plans for leading drills to help firefighters to learn and apply air management concepts and develop conscious habits for managing their air.

Such changes were not met without resistance, as can be seen within the revision and document history of *NFPA 1404*. During the 2006 revision of the standard, committee members charged departments with ensuring that firefighters' "[e]xit from an IDLH atmosphere should be before consumption of reserve," which deviated from the normative practice of waiting until the low air-alarm sounded to begin the process of exiting a structure (Bernocco et al., 2003, p. 66). While one NFPA member argued that the directive would "virtually [eliminate] work time," the committee voted to retain the change (NFPA, 2006, p. 1404-2).

## What Do Existing PPE Tell Us About Communication Design?

These case studies of protective flash hoods and SCBA ETOSI alarms provide a number of insights as to how communication design might be leveraged to improve existing and future PPE components. One of the most obvious is that introducing new wearable technologies will impact how firefighters interact within information-laden environments. Indeed, Haas (1998) argued that "the relationship between old and new technologies is complex and often fraught in practice" and warned researchers that "overly simple views of technology may lead to the bracketing of difficult questions…about technological development and equitable access" (p. 210). Within firefighters' practices of wearing protective hoods, we see deep seated tensions that are fundamentally about access. A choice to automate responsibility for firefighters' safety within a wearable interface is a choice that will impact the level of access she has to critical information that can inform her decision making.

From an UX and IxD perspective it seems reasonable that firefighters required time to adjust to and build trust with protective hoods because these wearables altered firefighters' access to sensory information and required firefighters to develop new ways of interacting with work environments. The widespread adoption of protective hoods within the fire-service today signals that these wearables have earned that trust. Yet, trust in these wearables is not monolithic: some firefighters continue to resist wearing these protective interfaces, some captains and lieutenants do not enforce the wearing of hoods, and some jurisdictions do not issue firefighters these components as a standard element of PPE. In this instance, wearing illustrates that an argument for protective hoods hinges on accepting the premise that increasing the thermal protective capacity of PPE increases firefighter safety, whereas the argument against protective hoods rests on the premise that retaining access to embodied sensory information increases firefighter safety.

Communication design matters with and for PPE because it offers theories, stances, and concepts that might help manufacturers, engineers, and practitioners reconcile these tensions. It makes sense for firefighters to desire both increased thermal protection and access to sensory information from PPE. As wearable interfaces, protective hoods obfuscate a form of sensory information firefighters have traditionally used to evaluate if work environments are unsafe. Consequently, the practice of wearing protective hoods obliges firefighters to work in and interact with environments in new ways (e.g., they can work amidst elevated temperatures without sustaining burns), and these new capabilities expose these workers to new risks (e.g., working in elevated temperature increases the heat-stress firefighters encounter). If reducing access to sensory-information is a consequence of increased thermal protection, communication designers might work to informate firefighters' work by creating UI that return information about the environmental hazards surrounding them through visual, aural, or haptic forms of feedback.

However, simply providing information may not be the solution. Our analysis of ETOSI illustrates that firefighters, as end users, might orient to wearables that informate their work in a range of ways in practice. While SCBA allowed firefighters to enter and work in locations that were previously untenable, they regularly worked until the low-air alarm sounded, which they interpreted to mean that they needed to begin exiting buildings. In many cases, firefighters had progressed so far into structures that when the ETOSI alarm sounded, they simply did not have enough air in their SCBA cylinders to escape safely. Consequently, firefighters routinely ran out of air because they had not developed—or had not been trained in—effective air management practices.

These tragedies presented an opportunity for UI redesign, but firefighters instead developed new practices for creating and interpreting information that would allow them to manage air while working on a limited air supply. Realizing this exigency, Bernocco and colleagues at Seattle Fire Department undertook a communication design campaign to teach firefighters how to effectively read and analyze the data that was available on SCBA air gauges. While the SCBA had been in use within the fire-service since the 1950s, it was not until the late 1980s that NFPA promulgated a standard that denoted that firefighters should be trained in air management and it was the late 1990s when the firefighters from Seattle began developing an air management program. Ultimately, this work gained such prominence that it influenced how members of fire service practice air management at a national level.

These examples suggest that, if the informating potential of technologies is to be realized, workers will need time, space, and resources to develop what Zuboff called intellective skills for making use of new forms of information. Put differently, end-users have a pivotal role within communication design, as Bernocco and colleagues (Gagliano et al., 2008) solved a communication design exigency that manufacturers, regulators, and prior wearers of the SCBA had not considered. Designers and manufacturers of smart-firefighting PPE, including devices that provide access to information about a firefighter's physiological performance, stand to gain much by utilizing a similar participatory design methodology (Spinuzzi, 2005) to mitigate against the possibility of repeating these mistakes in the future.

## SMART-FIREFIGHTING: ANTICIPATING COMMUNICATION DESIGN CHALLENGES IN NEXT-GENERATION PPE

The future of firefighting has arrived. Technologies like Globe's WASP, a set of firefighting turnout gear with an embedded array of sensors, could help incident managers intervene when individual firefighters are exposed to extreme physiological stress, and Scott Safety's Sight would allow firefighters to see in black-out, smoke-filled environments. Currently, the standing edition of *NFPA 1971* does not outline design standards for smart firefighting wearables, but the emergence of *NFPA 950: Standard on Data Development and Exchange for the Fire Service* (2015) and *NFPA 951: Guide to Building and Utilizing Digital Information* (2016) suggest that the fire-service is beginning to wrestle with the ways that information technologies will impact the profession. [3] These impacts will be consequential, as Grant and colleagues (2015) hypothesized: "[c]yber-physical systems will revolutionize firefighting" (p. xx). Indeed, *Research Roadmap for Smart Fire Fighting* (Grant et al., 2015) identified areas for future scientific and technical research in the area of firefighters' smart PPE, including areas in communication design such as IA, IxD, UX, and UI design. Regrettably, the authors noted that "although there is a substantial body of knowledge and research regarding user-centered design and usability principles, much of that information is not yet integrated into the standard design and development of today's firefighting systems" (p. 180). The emergence of smart-wearable PPE, then, might signal a kairotic opportunity for communication designers who specialize in UX, IA, UI, and IxD to influence the ways these technologies are designed for individuals working in industries such as the fire-service that require PPE. While we have focused on firefighters here, we maintain that some of tensions associated with wearing

PPE outlined here apply to the work performed by police officers, technical rescuers, emergency medical technicians, nurses, doctors, x-ray technicians, welders, and electricians.

In this section, then, we draw from our experiences working with and as firefighters to offer insights on four critical-tensions communication designers will need to consider while designing smart-wearable PPE capable of tracking physiological performance: (a) data types, access, and privacy; (b) information overload and sensory deprivation; (c) trade-offs: trusting and learning systems; and (d) organizational factors. As information technologies that automate the monitoring of a workers' physiological performance, smart-wearable PPE will produce streams of data that firefighters, supervisors, incident managers, chief executive officers, insurance providers, and medical providers have not previously had access. This information will informate the work that firefighters do. However, decisions about how, who, when, and why various stakeholders are granted access to data and information generated by these new interfaces will impact the ethical quality and usefulness of these systems.

## Data Types, Privacy, and Access

Wearable technologies capable of monitoring firefighters' physiological performance pose a variety of data, privacy, and access concerns. The intent of physiological monitoring is to increase firefighter safety and occupational longevity by collecting data that could be used to warn firefighters of underlying medical conditions or identify when work practices push firefighters into high-risk physiological states. Consequently, these technologies also have the potential to capture data that could be used to permanently remove an individual from firefighting activities. While system architects, fire-service leaders, and firefighters must appreciate the serious and consequential role physiological data could have in arriving at timely decisions about firefighters' short- and long-term readiness for duty, they must also consider the central role that medical experts play in determining individual firefighters' fitness for duty through medical monitoring programs as outlined in *NFPA 1582* (2013a). As a result, we argue that system architects should treat raw data as privileged medical information to ensure that it is only accessed by those with legal or medical necessity to do so. While some of the data that wearables collect might be classified as medical information and others as performance data, only medical information is legally protected by The Health Insurance Portability and Accountability Act (HIPAA), [4] which "addresses the use and disclosure" of protected health information.

Thus drawing careful distinctions about which types of physiological data should be classified as privileged medical information and building user interfaces or algorithms that act as black boxes to shield the raw data, while still communicating useful information about performance, would be one strategy system architects might utilize. One solution that could improve privacy would be to design UI that black boxes privileged medical data such as electrocardiograms, with keys that can be granted to medical personnel to unlock and access raw data when conditions warrant it. An interface like this would allow medical providers to make informed, timely medical decisions that could save firefighters' lives, while also protecting an individuals' privacy within the workforce.

Another UI solution that designers might consider would be to mirror the types of heads-up-displays found on many models of SCBAs today. These interfaces provide external lights that assign a green/go, yellow/caution, or red/danger status to firefighters' air level. A similar approach could be taken in UI design to communicate physiological performance to firefighters, officers, and incident managers, while leaving specific data points unknown. For instance, there are established cut points for oxygen saturation that indicate when a firefighter is likely to become incapacitated. UI could provide an early warning that would allow firefighters, team members, or incident managers to intervene before incapacitation occurs. Thus, data from physiological wearable technologies has promise to be a tool to inform performance, safety, and health.

Moreover, we see opportunities for collaborative research partnerships, such as ours, to leverage transdisciplinary expertise to collect data about firefighters' physiological and operational performance that could be used to develop evidence-based practices into decision-making sequences. Data could be anonymized for later use in after incident analyses or within fitness or training programs for organizations. For example, a crew of firefighters might be asked to describe how they would respond to a scenario where each member simultaneously encountered a caution status, if no other indicators suggested that the safety of their position might be compromised. Indeed, half of heart attacks have no symptoms, so it is plausible that a wearable could reveal a physiological response in a firefighter that could signal in a user interface that she needs additional medical observation and/or intervention. It is also plausible that an interface could signal an alarm in error.

## Information Overload and Sensory Deprivation

As members of hierarchically organized paramilitary organizations, firefighters work as individuals and in teams responsible for highly distributed and specialized work activities during fire response. Whereas truck companies perform functions like ventilation, search and rescue, and forcible entry, engine companies perform fire suppression and water supply functions. Line officers directly manage crews performing those functions, but incident commanders set the tone and strategy for a response and are responsible for ensuring top-sight over operations. Moreover, the fire environment encompasses sensory deprivation with low or no visibility and sensory overload creates dependence on the other senses because of the vision decrement, heat stress, altered hearing due to noise exposures, and physical demands of firefighting. Therefore, firefighters need access to specific forms of information at precise moments during an event to make appraisals about the safest and most effective tactics and strategies for achieving operational objectives, because each firefighter is responsible for performing highly specialized and distributed work.

Wearable technologies have the potential to provide firefighters with new forms of information, streamlining how they might interact with raw sensory- or environmental-data. UI could be designed to reduce the cognitive demands of firefighting by providing workers with just-in-time information that could technologically augment their sensory acumen. However, wearables also have the potential to burden firefighters by displacing existing knowledge making practices or giving them yet another data stream they must process. UI designers will need to take these factors into consideration while designing next-generation wearables.

After incident analyses demonstrate that information and communication challenges exist on firegrounds and often result in fatal outcomes. These reports tell us that as conditions deteriorate, firefighters often lose access to more global forms of situational awareness because each task becomes even more critical. Firefighters must rapidly process multiple information streams in such situations, but this work becomes more difficult as each stream takes on an increased level of gravity and requires a sense of additional care. Consequently, one way communication designers could help to improve the design of these systems is by "tracing the interaction dynamics that support . . . information network[s]" (Potts, 2014, p. 63) and identifying how new tools impact the practices firefighters utilize to make and distribute information across emergency scenes. For example, communication design researchers might use observations and interviews to conduct usability studies in training scenarios. Such studies might reveal how the information streams wearables supply interrupt, alter, and enrich firefighters' operational practices while searching for victims or advancing hose-lines. Do these information streams slow down critical work activities and decisions? Do they change the ways firefighters are attending to various forms of environmental and situational data?

Discovering ways to automate processing tasks to technologies and algorithms that passively offer firefighters a global view of work safety, so that they might concentrate more fully on performing critical tasks, sounds great in theory. In practice, identifying which and how information streams can be automated during the wide array of situated contexts that firefighters work will be extremely complex work for communication designers, firefighters, and system architects. Ideally, these wearable technologies should aim to "fit into the existing web of tacit knowledge, workflow, and work tools, rather than doing away with them" (Spinuzzi, 2005, p. 166). That is, wearables should offer interfaces which are minimally intrusive and feedback that is easily recognized and provides clear direction for required actions, but these messages cannot gloss over the distinct ways that front-line firefighters, line officers, and incident managers make use of discrete forms of information at different moments in an incident. In other words, just-in-time information is situationally responsive to the temporal, operational, and subjective needs of firefighters doing different types of work in a highly distributed work environment. For example, incident commanders are simultaneously responsible for (a) setting incident milestones, (b) articulating strategies for achieving milestones, (c) assessing progress towards those milestones, (d) maintaining a global view of the incident, (e) monitoring two or more radio channels, (f) physically observing and listening to the scene and fire behavior, (g) listening to reports from line officers/division managers, and (h) giving orders to units. There may be opportunities for system architects to augment, streamline, and black-box information streams, but these systems will need to undergo extensive usability testing to identify precisely how changes could adversely impact decision making processes or send unintended ripples throughout the existing information networks upon which firefighters rely.

## Trade Offs: Learning and Trusting Systems

As discussed in the case studies, firefighters have habitualized practices for listening and communicating on fireground situations, and they place deep trust in the reliability of these epistemic systems. When Nomex fabric was introduced, firefighters had to negotiate a serious value proposition: Was gaining additional thermal protection from flash hoods worth losing access to a form of sensory perception that firefighters had relied upon as a trusted form of knowing? Next generation wearables like Scott's Sight and Globe's WASP promise to augment, automate, and informate the ways firefighters will gather, interpret, and communicate information on firegrounds. Thus, another critical area communication designers will have to address is how PPE use will hinge on decisions about trade-offs such as: What data or information streams will be gained and/or potentially lost as these new wearables become widely available? Technological adoption will not be as simple as trading one tool for another, as the adoption of new systems will force firefighters to discard and adapt existing technologies, discard and adapt existing practices, and construct new practices that synthesize new and existing information streams. They will also have to build the type of trust in emergent technologies and practices that firefighters had bestowed in existing technologies and practices after decades of practice.

A secondary component of this challenge surrounds the ability to make time and space to train personnel in new systems. Due to stringent regulatory and certification standards, it is difficult for fire service organizations to maintain the status quo, let alone add new training and education programs. If the fire service is going to move to an evidence-based, data-centric model of practice, significant capital and labor inputs will be necessary. For example, when thermal-imaging cameras were introduced, it allowed firefighters to see heat within walls and to read the temperature of the fire. However, it took years of practice, experimentation, and use before firefighters began to fully realize the opportunities and limitations of these devices. Some jurisdictions had the cameras for years before firefighters began actually taking them off the truck and putting them into practice. Just as firefighters had to learn how to interpret information provided by the low-alarms, firefighters had to learn that thermal imaging cameras could not look through glass, but instead reflected an image like a mirror. Similarly, firefighters gained the ability to read the temperature of a fire and see how fire traveled through spaces in zero-visibility work environments, but they also had to develop ways of translating those forms of data to information that could help firefighters make different or new decisions about practice. Wearables will pose similar challenges, and communication designers, system architects, and fire service leaders will need to think about how workers of different ranks tasked with distinct functions will learn how to use information streams strategically while working in situated environments.

## Organizational Factors

A final critical area system architects will need consider in smart wearable PPE is related to the composition of organizations. Campaign designers have been encouraged to consider the physical, information, and social structure of an organization when designing workplace health interventions (Harrison et al., 2011). This "interaction environment"—the physical, information, and social space—in which communication between organizational members occurs is a helpful frame for considering how new technologies can impact socio-technical environments more broadly. In particular, prior research suggests that factors such as generational differences (e.g., Lauricella, Cingel, Blackwell, Wartella, & Conway, 2014), blue-collar work identity and practices (e.g., Sauer, 2003; Gibson & Papa, 2000), and hierarchy (e.g., Winsor, 2000) can have a significant influence on the interaction environment, which shapes how work is enacted within occupational organizations. In other words, how users interact with a tool is not only shaped by the UI, but also through the cultural and organizational values that might impact how users within an organization understand and orient to a tool.

To elaborate, data generated by wearables have a range of implications for individuals at different career stages. These generational differences may influence the comfort-level organizational members have in adopting these technologies. As Zuboff explained, the “textualization of work” led to greater “visibility” about work, which prompted “workers’ feelings of apprehension” (Burton-Jones, 2014, p. 76). Firefighters nearing the end of their careers or who have been exposed to physiological, environmental, and psychological stress may view collecting this data as creating new, unexpected performance requirements, especially if physiological data could result in them being removed from the line of duty or even losing their job when they are close to receiving a pension. Conversely, previous research has shown that motivation to use technology is influenced by age (Lauricella, Cingel, Blackwell, Wartella, & Conway, 2014), thus younger firefighters may be more apt to see the potential benefits of smart PPE.

Moreover, firefighters have historically embraced blue-collar traditions as a profession, which might be a barrier to the adoption of smart wearable PPE that introduces more data and information to the ways firefighters experience work. As Gibson and Papa (2000) explain, blue-collar work has traditionally been associated with physical labor where white-collar work is characterized as professional or managerial. Within the fire service, individuals are assimilated into a blue-collar culture. Often times individuals are assimilated into blue-collar jobs before they even enter an organization through “organizational osmosis.” Organizational osmosis is the “seemingly effortless adoption of the ideas, values, and culture of an organization on the basis of preexisting socialization experiences” (Gibson & Papa, 2000, p. 79). In other words, many blue-collar workers, like firefighters, often enter their professions with existing conceptions of and expectations for their organizational cultures. Culturally, firefighting is seen as a heroic profession—a career where individuals are exposed to risk, but where they also have the potential to save lives. No one becomes a firefighter under the auspices that it is a low-risk, easy work job. However, as one of the members of our team shared, today’s generation of firefighters are told “no” much more. Firefighters sign up for a hero job and spend the bulk of their academy training doing dirty work and learning to fight fires. However, this does not match the mundane reality of daily work in the position, as the majority of calls firefighters take are medical, and many positions require firefighters to spend extensive time composing and reading reports, proposals, contracts, budgets, schedules, inspections, and records.

Finally, within the fire service, blue-collar firefighters must interact with management who are considered white-collar. Yet, as Winsor (2000) suggests, work must often cross these professional divides. Smart wearable PPE might be an opportunity to revisit and rethink what and how such hierarchies mean for the work of front-line, supervisory, and administrative firefighters, but it also has the potential to reify such divisions. For instance, front-line blue-collar firefighters might perceive such technologies as the latest attempt by white-collar leaders to micromanage their work. Indeed, Winsor found that work orders “initiate a situation in which certain work gets done, they do not determine that work by themselves” (p. 169). Similarly, in the case of wearables, the data that may be generated may initiate an action (e.g., removing a firefighter from a scene because their oxygen levels are too low), but for that data to be useful to workers it must be “supplemented by a wide variety of material and social arrangements” (p. 169). If and as smart-wearables are adopted, it will be essential to trace how they will impact the material and social arrangements that presently govern labor in the fire service and to consider how data produced by these designs will be used and translated across the hierarchies.

## CONCLUSION

Although firefighters’ PPE might be understood as an assemblage of wearable technologies designed to protect firefighters from the occupational hazards associated with working in environments that are immediately dangerous to life and health (IDLH), it is important to remember that research has shown that modern innovations in firefighting PPE have exposed firefighters to increased risks associated with working in such environments (Smith et al., 1998; Smith et al., 2015; Carter, et al., 2007; Soteriades, 2011). The blends of heat resistant polybenzimidazole kevlar and/or nomex fibers used in firefighters’ bunker pants, coats, and flash-hoods shield firefighters from elevated temperatures, but firefighters can absorb and inhale the chemical toxins stored in this gear when it is exposed to heat (Fent et al., 2014). SCBA allows firefighters to breathe in environments filled with toxic smoke and superheated gases, but it also “permits firefighters to go ‘deeper and deeper’ into involved structures” (Teele, 1996) increasing their risk of sustaining thermal or cardiovascular injuries (Soteriades et al., 2011). An array of safety sensors has been built into SCBA to provide firefighters with feedback that can save their lives, but firefighters often ignore the audible alarms emitted by personal alert safety system devices that signal that a firefighter may be trapped or incapacitated (Jiang, 2004) or work into and beyond the point when EOSTI signal an alert that a firefighter is running low on air (Bernocco et al., 2008).

As communication designers seek to influence the design of smart-PPE, they will be well served by carefully attending to the ways these “reality shifting” (Pedersen, 2013) designs could impact how workers across industries have traditionally constructed and communicated information within occupations. Indeed, new forms of firefighting PPE have been integrated into the occupation before, and they have created new communication challenges for these workers by exposing them to new risks while shielding them from those risks that were previously known. Communication designers should consider how UX, IxD, IA, and UI might be leveraged as sites where workers’ practices are not only automated, but also informated to shield against repeating these mistakes.

Moreover, communication designers and system architects should consider deeply the ethical, social, and economic implications associated with introducing physiological-monitoring devices to workplaces. There are certainly benefits that are associated with the ability to monitor and track firefighters’ individual exposure to risk, toxins, and physiological/psychological stress, but we assert that safeguards should be designed to privilege foremost the needs and concerns of those of workers—regardless of industry—who are asked to bear the greatest risk and consequently endure the repercussions of working in hazardous environments. A one-size fits all approach to the design of physiological wearables will neither serve the interests of workers, nor the organizations, communities, and constituencies they serve.

For instance, within the fire-service there is an expectation that firefighters will exert a 150% effort every time. Firefighters are expected to be willing to put it all on the line; to work stoically through injury, pain, and discomfort; and to put others before self. Such expectations, we would argue, have been under-appreciated as they expose firefighters to disproportionate levels of risk in comparison to other types of workers. Regardless of their exposure relative to others working in the occupation, firefighters are expected to carry on this intensity of work until they have accumulated an arbitrarily defined length of service to qualify for retirement benefits. Consequently, physiological-wearables could be used as gate-keeping devices within organizations. Physiological-wearables could be used as tools that allow those who are fit and able to mark peer affected by a physical ailment as outsiders. And, physiological-wearables could also be used to help firefighters identify, treat, and manage physical conditions that enable them to prolong their careers.

Amplifying the amount of medical and physiological monitoring firefighters are exposed to could carry unforeseen social, cultural, and economic consequences. Our experience working with fire-service organizations suggests that many jurisdictions do not participate in or offer firefighters access to occupational health and medical monitoring programs. We suspect that in some cases this is because these jurisdictions simply do not have resources within their operating budget to afford the costs of these programs. However, there are other instances wherein communities and leaders do not offer access to medical monitoring because the programs could potentially disqualify individuals from working within their organizations. In the United States, nearly 70% of firefighters are members of volunteer departments (NFPA, 2017, p. v), and jurisdictions that rely on volunteers are finding it increasingly difficult to recruit individuals willing to perform the types of dangerous work fire-service organizations are called on to perform (NVFC, 2015, p. 3). Integrating physiological monitors in the fire-service amidst increasingly stringent medical standards (NFPA, 2013a) will render visible data that will exclude individuals who have answered the call to serve their communities from continuing to serve. It will also mean that firefighters' serving in both career or volunteer departments who possess or develop disqualifying medical conditions could be detected with greater regularity. Disqualifying firefighters from these organizations—many of whom serve within departments located in rural, geographically remote, and less-affluent communities—would result in those communities having less access to personnel necessary for staffing the emergency-services they rely upon.

Ultimately, designers and users of physiological wearables must appreciate that the data generated by these devices could impact how insiders and outsiders might orient to and draw conclusions about what the data means. It might be possible to design systems that informate the work that individuals do (e.g., to send an alert to a firefighter that she might be working into a high-risk physiological state, so that she might reduce her effort), but organizational cultures might cause workers in mission-driven occupations such as firefighting or nursing apprehension about whether it is appropriate to actually decrease their effort. Similarly, if wearable physiological monitoring systems collect data that signal to managers such as incident commanders that workers such as firefighters should take a break or be removed from working at an incident, it is likely that fellow workers will question whether their peers are fit for duty even if they have been approved by a medical professional. System designers can ensure that data and information generated about firefighters from wearables is made private or confidential, but these systems will capture data that will be or could be used in public forums—and those uses will impact how firefighters are viewed by colleagues, administrators, medical personnel, lawyers, and publics.


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## END NOTES

[1] See Burton-Jones (2014) for a comprehensive overview of Zuboff's theory of information technology that richly maps how concepts within this theory interrelate.

[2] These conversations were conducted after we received IRB approval (Colorado State University IRB Exempt #017-18H).

[3] These national standards offer guidance on the design of sustainable and interoperable data, databases, and information systems.

[4] HIPAA is a federal law within the U.S. that seeks to balance the privacy of patients' health information and the appropriate use this information for provision of healthcare services. HIPAA allows patients to control how healthcare providers and health plans disclose and disseminate data and information about their health with third parties. It is imperative that data captured by physiological wearables in occupational settings such as the fire service be handled with care, as this data could be considered both health and performance data. That is, the data could be used within the continuum of a diagnosis process or within the continuum of an incident command process.

## REFERENCES


Alam, M.M., & Hamida, E.B., (2014). Surveying wearable human assistive technology for life and safety critical application: Standards, challenges, and opportunities. *Sensors, 14*, 9153-9209.

Amidon, T.R., Williams, E., Lipsey, T., Henry, K., Callahan, R. (2016, October). Adaptive challenges: A symposium on work, knowledge, and safety in the U.S. fireservice. Symposium conducted at Colorado State University, Ft. Collins, CO. Retrieved from goo.gl/hLE2q6

Batalin, M., Yuen, E., Dolezal, B., Smith, D., Cooper, C., & Mapar, J. (2013). PHASER: Physiological health assessment system for emergency responders. 2013 *IEEE International Conference on Body Sensor Networks*.

Bernocco, S., Phillips, C., Jose, P., & Yob, C. (2003, April). Train in "the rule of air management." *Fire Engineering*, 57-66.

Besthoff, L. (2015, May). Hartford Fire Department changing equipment after firefighter death. NBC Connecticut. Retrieved from http://www.nbcconnecticut.com/troubleshooters/Hartford-Fire-Department-Changing-Equipment-After-Firefighter-Death-304653211.html

Blythe, S. Grabill, J., & Riley, K. (2008). Action research and wicked environmental problems: Exploring appropriate roles for researchers in professional communication. *Journal of Business and Technical Communication, 22*(3), 272-298.

Bonfiglio, A., Curone, D., Secco, E.L., Magenes, G., & Tognetti, A., (2010). Emergency and work. In A. Bonfiglio & D. DeRossi (Eds.), *Wearable monitoring systems* (pp. 205-219). New York, NY: Springer.

Brydon-Miller, M., Greenwood, D., & Maguire, P. (2003). Why action research? *Action Research, 1*(1), 9-28.

Burton-Jones, A. (2014). What have we learned from the Smart Machine? *Information and Organization, 24*(2), 71-105.

Carter, J.M., Rayson, M.P., Wilkinson, D.M., Richmond, V., & Blacker, S. (2007). Strategies to combat heat strain during and after firefighting. *Journal of Thermal Biology, 32*(2), 109-116.

Chang, J.S.K., Love, O., Henry, M.J., Corley, C., Burtner, R. (2015). The heroes' problems: Exploring the potentials of Google Glass for biohazard handling professionals. CHI'15 Extended Abstracts, 1531-1536.

Dolezal, B.A., Barr, D., Boland, D.M., Smith, D.L., & Cooper, C.B. (2015). Validation of the firefighter WFI treadmill protocol for predicting VO2 max. *Occupational Medicine, 65*, 143-146.

Dolezal, B.A., Boland, D.M., Carney, M., Abrazado, D.L., & Cooper, C.B. (2014). Validation of heart rate derived from a physiological monitor-embedded compression shirt against criterion ECG. *Journal of Occupational and Environmental Hygiene, 11*, 833-939.

Donovan, R., Nelson, T., Peel, J., Lipsey, T., Voyles, W., & Gay Israel, R. (2009). Cardiorespiratory fitness and the metabolic syndrome in firefighters. *Occupational Medicine 59*(7), 487-492.

Fals-Borda, O. (1991). Some basic ingredients. In O. Fals-Borda & M. A. Rahman (Eds.), *Action and knowledge: Breaking the monopoly with participatory action research* (pp. 3-12). New York: Apex.

Fent, K.W., Evans, D.E., Booher, D., Pleil, J.D., Stiegel, M.A., Horn, G.P., et al. (2015). Volatile organic compounds off-gassing from firefighters' personal protective equipment ensembles after use. *Journal of Occupational and Environmental Hygiene, 12*(6). 404-414.

Florea, G., Dobrescu, R., Popescu, D., & Dobrescu, M. (2013). Wearable system for heat stress monitoring in firefighting applications. In S. Lopez (Ed.), Recent Advances in Computer Science and Networking: *Proceedings of the 2nd International Conference on Information Technology and Computer Networks* (ITCN'13) (pp. 129-134).

Gagliano, M., Phillips, C., Jose, P., & Bernocco, S. (2008). *Air management for the fire service.* Tulsa, OK: PennWell Corporation.

Gibson, M.K., & Papa, M.J. (2000). The mud, the blood, and the beer guys: Organizational osmosis in blue-collar work groups. *Journal of Applied Communication Research, 28*(1), 68-88.

Gouge, C. & Jones, J. (2016). Wearables, wearing, and the rhetorics that attend to them. *Rhetoric Society Quarterly, 46*(3), 199-206.

Grant, C., Hamins, A., Bryner, N., Jones, A., & Koepke, G. (2015). *NIST special publication 1191: Research roadmap for smart fire fighting*. NIST/NFPA.

Haas, C. (1998). On the relationship between old and new technologies. *Computers and Composition, 16,* 209-228.

Halton, B. (2013. March). Editor's opinion: The majority opinion. *Fire Engineering, 6*.

Halton, B. (2012, September). Letters to the editor. *Fire Engineering,* 52-56.

Harrison, T. R., Morgan, S. E., Chewning, L., Williams, E. A., Barbour, J., Di Corcia, M. J., & Davis, L. (2011). Revisiting the worksite in worksite health campaigns: Evidence from a multi-site organ donation campaign. *Journal of Communication, 61*, 535-555.

Hasenmeier, P. (2008, June). The history of firefighter personal protective equipment. *Fire Engineering.* Retrieved February 28, 2017, http://www.fireengineering.com/articles/2008/06/the-history-of-firefighter-personal-protective-equipment.html

Hirst, J. (1884). On the methods used by the Romans for extinguishing conflagrations. *The Archaeological Journal, 41*, 155-167.

Hensler, B. (2011). *The crucible of fire: Nineteenth-century urban fires and the making of the modern fire service.* Washington, DC: Potomac Books.

Jack, J. (2016). Leviathan and the breast pump: Toward an embodied rhetoric of wearable technology. *Rhetoric Society Quarterly, 46*(3), 207-221.

Jiang, X., Hong, J.I., Takayama, L.A., & Landay, J. (2004). Ubiquitous computing for firefighters: Field studies of prototypes of large displays for incident command. CHI'04: *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 679-686.

Johnstone, J.B.G., Graveling, R.A., Butler, D.O., Butler, M.P., Cowie, H.A., & Hanson, M.A. (1995). *The effectiveness and safety of fire hoods*. Edinburg, Scotland, UK: Institute of Occupational Medicine.

Kessler, M.M. (2016). Wearing an ostomy pouch and becoming an ostomate: A kairological approach to wearability. *Rhetoric Society Quarterly, 46*(3), 236-250.

Koohi, H., Nadernejad, E., Fathi, M. (2010). Employing sensor network to guide firefighters in dangerous area. *IJE Transactions: SID, 23*(2), 191-202.

Lauricella, A.R., Cingel, D., Blackwell, C., Wartella, E., & Conway, A. (2014). Mobile generation: Youth digital media use in the age of technology. *Communication Research Reports, 34*(4) 1-8. DOI: 10.1080/08824096.2014.963221

Li, K., Lipsey, T., Leach, H.J., & Nelson, T.L. (2017). Cardiac health and fitness of Colorado male/female firefighters. *Occupational Medicine 67*(4), 268-273.

Meloncon, L., & Frost, E. (2015). Charting an emerging field: The rhetorics of health and medicine and its importance in communication design, *Communication Design Quarterly, 3*(4), 7-14.

Mirel, B. (1998). 'Applied constructivism' for user documentation. *Journal of Business and Technical Communication, 12*(1), 7-49.

Muller, M. J. (1997). Ethnocritical heuristics for reflecting on work with users and other interested parties. In M. Kyng & L. Mathiassen (Eds.), *Computers and design in context* (pp. 349-380). Cambridge, MA: MIT Press.

Muller, M. J. (1999). Invisible work of telephone operators: An ethnocritical analysis. *Computer Supported Cooperative Work, 8*(1-2), 31-61.

Nardi, B.A., & Engeström, Y. (1999). A web on the wind: The structure of invisible work. *Computer Supported Cooperative Work, 8*(1-2), 1-8.

NFPA. (2015). *NFPA 950: Standard for Data Development and Exchange for the Fire Service*. Quincy, MA: NFPA.

NFPA. (2016). *NFPA 951: Guide to Building and Utilizing Digital Information.* Quincy, MA: NFPA.

NFPA. (2013a). *NFPA 1582: Standard on Comprehensive Occupational Medical Program for Fire Departments.* Quincy, MA: NFPA.

NFPA. (2013b). *NFPA 1971: Standard on Protective Ensembles for Structural Fire Fighting and Proximity Fire Fighting.* Quincy, MA: NFPA.

NFPA. (2013c). *NFPA 1989: Standard on Breathing Air Quality for Emergency Services Respiratory Protection.* Quincy, MA: NFPA.

NFPA. (1973). *Report on committee on fire department equipment. Tentative Standard for Protective Clothing for Fire Fighters 19A-T* [NFPA 1971, 1973 edition]. Quincy, MA: NFPA.

NFPA. (1991) Report of Committee on fire service protective clothing and equipment. *NFPA 1971 Standard on Protective Clothing for Structural Fire Fighting.* Quincy, MA: NFPA.

NFPA. (1989). Report of committee on fire service training. *NFPA 1404: Standard for Fire Department Training and the Use of Respiratory Protection Equipment.* Quincy, MA: NFPA.

NFPA. (2006). Report of committee on fire service training: Report on comments (F2005). *NFPA 1404: Standard for Fire Service Respiratory Protection Training.* Quincy, MA: NFPA.

NFPA. (2017). U.S. Fire Department Profile: 2015. Quincy, MA, NFPA.

NIOSH. (2017). Career fire fighter dies from an out-of-air emergency in an apartment building fire—Connecticut. Death in the line of duty: F1014-19. Morgantown, WV: NIOSH Fire Fighter Investigation and Prevention Program.

NIOSH. (1999). Eight-alarm fire in 27-story high-rise apartment building for the elderly nearly claims the life of one fire fighter—Missouri. Injury in the line of duty: 98-F26. Morgantown, WV: NIOSH Fire Fighter Investigation and Prevention Program.

NIOSH. (2016). Lieutenant and fire fighter die and 13 fire fighters injured in a wind-driven fire in a brownstone—Massachusetts. Death in the line of duty: F2014-09. Morgantown, WV: NIOSH Fire Fighter Investigation and Prevention Program.

NIOSH. (2001). Supermarket fire claims the life of one career fire fighter and crucially injuries another career fire fighter—Arizona. Death in the line of duty: F2001-13. Morgantown, WV: NIOSH Fire Fighter Investigation and Prevention Program.

NVFC. (2015). Volunteer Firefighter Recruitment and Retention Formative Research Results: Prepared for National Volunteer Fire Council. SalterMitchell, Inc.

OSHA. (2015). Inspection #999065 [Hartford Fire Department]. Retrieved from goo.gl/F8Pikm

Pedersen, I. (2013). *Ready to wear: A rhetoric of wearable computers and reality-shifting media.* Anderson, SC: Parlor.

Piatti, J.G., & Frost Piatti, S. (2002). Firefighting memorabilia. *The Journal of Antiques and Collectibles.* Retrieved from http://journalofantiques.com/2002/features/collecting-firefighting-antiques-memorabilia/

Potts, L. (2014). *Social media in disaster response: How experience architects can build for participation.* London, UK. Routledge.

Prezant, D.J., Malley, K.S., Barker, R.L., Guerth, C., & Kelly, K.J. (2001). The impact of protective hoods and their water content on the prevention of head burns in New York City firefighters: laboratory tests and field results. *Journal of Burn Care Rehabilitation*, *22*(2), 163-164.

Reason, P., & Bradbury, H. (Eds.). (2001). *Handbook of action research: Participative inquiry and practice*. London: Sage

Sauer, B. (2003). *The rhetoric of risk: Technical documentation in hazardous environments*. Mahwah, NJ: Lawrence Erlbaum Associates.

Scott, J. B., Segal, J. Z., & Keranen, L. (2013). The rhetorics of health and medicine: Inventional possibilities for scholarship and engaged practice. *POROI, 9*(1), Article 17.

Simmons, W. M. (2007). *Participation and power: Civic discourse in environmental policy decisions*. Albany, NY: SUNY Press.

Spinuzzi, C. (2005). The methodology of participatory design. *Technical Communication, 52*, 163-174.

Smith, DL., & Petruzzello, S.J. (1998). Selected physiological and psychological responses to live-fire drills in different configurations of firefighting gear. *Ergonomics 41*(8),1141-1154.

Smith, D.L., Haller, J.M., Dolezol, B.A., Cooper, C.B., & Fehling, P.C. (2014). Evaluation of a wearable physiological status monitor during simulated fire fighting activities. *Journal of Occupational and Environmental Hygiene*, *11*(7), 427-433

Soteriades, E. S., Smith, D. L., Tsismenakis, A. J., Baur, D. M., & Kales, S. N. (2011). Cardiovascular disease in US firefighters: A systematic review. *Cardiology in Review, 19*(4), 202-215.

Stake, R.E. (2005). Qualitative case studies. In N.K. Denzin & Y.S. Lincoln (Eds.), *The Sage handbook of qualitative research* (pp. 443-466). New York, NY: Sage.

Swarts, J. (2013). How can work tools shape and organize technical communication. In J. Johnson-Eilola & S. A. Selber (Eds.), *Solving problems in technical communication* (pp. 146-164). Chicago: University of Chicago Press.

Teele, B.W. (1996) NFPA standards on structural fire fighting protective clothing. In J.R. Lawson & N.H. Jason (Eds.), *NIST Special Publication 911: Firefighter Thermal Exposure Workshop: Protective Clothing, Tactics, and Fire Service PPE Training Procedures*.

Teston, C. (2016). Rhetoric, precarity, and mHealth technologies. *Rhetoric Society Quarterly, 46*(3), 251-268.

United States. (2004). The Health Insurance Portability and Accountability Act (HIPPA). Washington, DC: U.S. Dept. of Labor, Employee Benefits Security Administration.

United States Navy/Vazquez, J. (Photographer). (2014, Nov. 3). USS Dewey (DDG105)[photograph of firefighter donning protective hood]. Retrieved from goo.gl/jHZNf3

United States Navy/Price, R.S. (Photographer). (2016, June, 26). 160628-FQ994-100 [photograph of firefighter inserting SCBA regulator into face piece]. Retrieved fromgoo.gl/nDwXa6

Williams, E., & Callahan, R. (2016, August). Leveraging after action reviews: Learning in a high reliability organization. Presentation at Fire-Rescue International, San Antonio, TX.

Winsor, D. A. (2000). Ordering work: Blue-collar literacy and the political nature of genre. *Written Communication, 17*(2), 155-184.

Zuboff, S. (2015). Big other: Surveillance capitalism and the prospects of an information civilization. *Journal of Information Technology, 30*(1), 75-89.

Zuboff, S. (1988). *In the age of the smart machine: The future of work and power.* New York, NY: Basic Books, Inc.