# Sensors@Work

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# Chapter 9

## General discussion

## 9.1 | Aim and evaluation of main findings

The overarching aim of this dissertation was to contribute to a sustainable workforce by making the (mis)balance between workload and work capacity measurable with sensor technologies. To realize this, the first step was designing and testing sensor technologies to make workload and capacity measurable and secondly to measure the balance between workload and capacity. Then, by utilizing data gained from sensor technologies, appropriate interventions can be made to align physical workload and individual work capacity more closely for each worker. This strategy was applicable to all kinds of workers. Throughout this dissertation, the focus was on monitoring (1) the mechanical workload, (2) the energetic workload, and (3) the reaction to heat exposure of physically active and/or office workers.

### 9.1.1 | Physically active workers

For physically active workers, the main problems include an unfavourable working posture, heat exposure, and physical fatigue due to a high physical workload (Spook, et al., 2019; Andersen, et al., 2016). The following monitoring technologies were designed and/or studied:

- a sensor suit to monitor working postures and movements, muscle activity and automatically estimating the internal mechanical workload (Chapter 3);
- a headset which analyses breathing gas to monitor internal energetic workload (Chapters 4 and 5);
- a wearable body thermometer to monitor the internal reaction to external heat exposure (Chapter 6 and 7).

With a sensor suit of inertial magnetic measurement units and an artificial neural network (ANN), the working posture and movements and muscle activity was measured, and the related low back load was estimated. Different intensity and variation levels of the moment in lumbar load exposure could be distinguished with this method between light and heavy tasks as well as between static and dynamic tasks. It was concluded that the sensor system and ANN indeed showed differences in the physical load exposure in the lumbar region consistent with the perceived intensity levels and character of the work task. This study showed the validity of this monitoring system for physically demanding occupations.

A portable headset has been developed to analyse breathing gases and determine the energetic workload of physically active workers. A proof-of-concept experiment confirmed the headset’s results and showed that it was more valid compared to oxygen consumption estimated on the basis of heart rate. The headset was found to be comfortable, presented a low breathing resistance, and did not hinder communication. The headset provides a compromise between the cumbersome mouth mask and the relatively inaccurate heartrate monitoring. The present version is not yet completely validated, but its potential is supported and indicates opportunities for further professionalization.

A wearable thermometer was studied to monitor body temperature and heat strain of physically active workers. First, the thermometer was validated against the medical standard, an ear canal temperature reading. Without correction, the wearable was not accurate. With a correction factor applied, however, the accuracy of the thermometers was confirmed at rest, but not during working conditions. The Cosinuss° thermometer was comfortable and interfered minimally (or not at all) during work. Second, the thermometer was validated against the scientific standard, an invasive temperature pill. The validity of the thermometer was not confirmed in this scenario, and thus this wearable thermometer is an invalid method for measuring the core temperature of firefighters when in working conditions. However, if the reliability of the thermometer can be improved, it could play a role in predicting core temperature and heat storage as part of a multivariable system.

### 9.1.2 | Office workers

For office workers, the main problem is an unfavourable working posture causing too high or too low local physical loads on the body due to inactivity. The working posture and duration, and perceived musculoskeletal discomfort were monitored with a 'smart' sensor chair (Chapter 2). The intervention of the sensor chair was a tactile feedback signal given to the worker whenever prolonged working in an unfavourable posture was detected. Although this feedback signal led to small or insignificant changes, insight into individual reactions to workplace health promoting feedback was provided. And this chair proved to be a useful tool to monitor sitting behaviour in the workplace in a non-obstructive manner.

## 9.2 | Relevance

The potential value of this dissertation is that the summarization of data surrounding sensor technologies in the workplace will help to realise a sustainable workforce in the future (Kadir, et al., 2019; Warmelink, et al., 2020; Waschull, et al., 2020; Papagiannidis & Arikyan, 2020; Edirisinghe, 2019; Kuruganti, 2019; Ullrich, et al., 2019). The useful results of this research were achieved by (1) the collaboration with specialists of different fields of expertise and (2) an in-depth needs assessment as a basis for the personalized and user-driven designs. Additional strengths of this dissertation are (3) a diversity of focus areas within aspects of physical workload, (4) the focus on individual responses instead of a group focus, and (5) the discovery of the ethical agenda related to the design and implementation of sensor technologies.

This dissertation offers a broad analysis of the needs and applications of sensor technologies in the workplace. These newly designed technologies range from scratch up to the application of commercially available technologies. A strength is their validation in a variety of workplaces (Havenith & Heus, 2004) or, if not yet suitable, under lab conditions. The studies discussed herein helped to gain useful insight into the usability and implementation of the systems and provided user-centred input to optimize the technologies.

These health-promoting technologies in the workplace will help to lower the workload if needed and may improve the workability and safety of workers (Lee, et al., 2020; Yang & Ahn, 2019; Bowen, et al., 2019). Several of the presented technologies can already contribute to monitor the workload and work capacity and assess the individual physiological response to the workload.

All four technologies show potential to objectively monitor individual response to the workload. By combining these technologies, individual internal load, physiological responses to heat exposure, energetic strain, and mechanical strain can be investigated per individual. Based on the output of these technologies, the tasks or working conditions can be adjusted, or interventions can be designed to align the mechanical and energetic load to prevent structural overload, discomfort or disability, and other health problems (Panel on Musculoskeletal Disorders and the Workplace, et al. 2001). They can vary from simple feedback (Punt, et al., 2019) provided via a smartphone or smartwatch to exoskeletons that take over a part of the workload.

The acceptance of the sensor and intervention technologies into the workplace is a very important criterion for success. These are discussed as follows. First, evidence about the technologies to objectively measure has been proven. Second, the technologies could contribute positively to the safety of the workplace and workers. Third, it has been explored if the workplace offers workers a positive and safe climate to act autonomously (Jacobs, et al., 2019; Palm, 2009; Johnson & Powers, 2005). In addition, the first steps for ethical implementation were provided.



The presented sensor and intervention technologies are widely applicable. Aside from monitoring work-related factors, they could be utilized in health care for prevention of illness or a fallback after rehabilitation therapy and could also be used in sports training. These wearable and non-invasive technologies could contribute to diagnostics and treatment that ultimately improve the quality of health care through (remote) monitoring (Patel, et al., 2012).

## 9.3 | Evidence of devices

The different kinds of technologies that have been designed fulfil the goals set at the start of this study.

- They monitor individual physiological responses to the workload in an objective manner according to the models in Figures 1.1 and 1.2 (Chapter 1) (Panel on Musculoskeletal Disorders and the Workplace, et al., 2001; Heerkens, et al., 2004).
- Physically demanding occupations can be monitored as well as office workers.
- Workers can be monitored over long periods of time instead of only in snapshots.

The sensor technologies investigated in this dissertation fulfil the requirements of workers and employers.

- The devices provide information about the individual physiological response to the workload.
- The devices do not interfere with workability and are safe in use.
- The devices are non-obstructive and easy-to-use.
- Except for the sensor chair, the devices are wearable.
- The devices can monitor a broad range of workers.

In terms of Technology Readiness Level (TRL) (Straub, 2015; Altunok & Cakmak, 2010) the following levels have been realized.

- The breathing gas-analysing headset started with a concept (proof-of-principle; TRL 2). After analytical and experimental examination of the critical function and the development of a proof-of-concept (TRL 3), the technology was validated in a lab study (TRL 4).
- The studies about the wearable thermometer started with the development of proof-of-principle (TRL 2) and proof-of-concept (TRL 3). The technologies were validated in lab studies (TRL 4) and in real-life working conditions (TRL 5 and 6).
- The sensor suit and ANN-based method started with a basic validation was performed in lab environment (TRL 4). Then, the technology was validated in the real-life working environment (TRL 5) and the function of the technology was demonstrated (TRL 6).

- The office chair was validated in an operational environment demonstrating its functioning (TRL 7). For monitoring sitting behaviour, its function was demonstrated (TRL 8) and its technological development is currently complete (TRL 9).

## 9.4 | Further testing

It is uncertain if all requirements will be met by all technologies that are designed. Thus, further testing is required. Future research needs to focus on the validity, reliability, and usability of these technologies for their purpose as objective monitoring tools.

### 9.4.1 | Breathing-gases analysis

The proof-of-concept experiment of the breathing gas-analysing headset showed that the usability of the headset is promising (Chapter 5). To further study the validity and usability, the professionalized prototype should be studied in real-life working conditions (Havenith & Heus, 2004) among different types of physically active (and office) workers. To go from the lab studies (TRL 4) to validation in real-life working conditions (TRL 5), the proof-of-concept needs to be optimized into a prototype for validation in the field.

### 9.4.2 | Heat stress

After validation in lab studies (TRL 4) and real-life working conditions (TRL 5 and 6), the thermometer did not work properly and the technology concept need to be reformulated (TRL 2). The wearable thermometer needs to be optimized to increase the accuracy of the predicted heat stress in an objective manner. A reliable instrument capable of predicting core temperature instead of measuring tympanic or aural temperature is preferred. An alternative is the extension of the non-invasive thermometer to a multiparameter system. This would increase the validity and reliability to objectively predict core temperature and heat stress during physically active work. New research and developments (Kim, 2018; Apykhtin, et al., 2018; Diaz-Piedra, et al., 2019; Chaglla, et al., 2018) should investigate the potential of such a multiparameter system. Also, individual differences in the development of heat stress should be taken into account. For workers using communicating systems, the wearable thermometer needs to be integrated with hearing protection and/or communication systems.

### 9.4.3 | Working posture and lumbar load exposure

The sensor suit and ANN-based method started with a basic validation was performed in lab environment (TRL 4) (Baten et al., 2008-2018) and validation among the real-life working environments of the users (TRL 5). Thus, the function of the technology was demonstrated

(TRL 6). However, the current system is not yet usable in the uncontrolled real-life working conditions. Large amount of data could not be analysed due to data-acquisition error during essential trials (Chapter 3). And the mechanical design of the system needs to be improved by integrating the sensors in the work clothes. So, the sensor system and software require further development into a prototype. This prototype must be usable in working conditions to allow validating the system in an operational working environment (TRL 7).

### 9.4.4 | Sitting behaviour

The function of monitoring sitting behaviour with the sensor chair has been demonstrated (TRL 9). The intervening feedback signal requires additional investigation and development to move from the theoretical basis (TRL 4) to a demonstrated working feedback signal (TRL 9).

## 9.5 | Further developments

Some requirements are not met yet. More research and design are required to fulfil the following open standing requirements and needs of the workers and employers.

### 9.5.1 | Feedback and behavioural awareness

Workers want to become aware about their own working behaviour (Patel, et al., 2012) and would like to receive personalized real-time feedback (Spook, et al., 2019). Like the smart chair, all monitoring technologies should be equipped with a feedback system. More research is needed to optimize and develop new feedback systems regarding how they can be linked to ergonomic guidelines and signalled to the worker in an easy-to-use yet meaningful manner (Spook, et al., 2019). This should make the workers aware of their working behaviour and offer them an opportunity to improve their behaviour if needed. This can only be achieved by interdisciplinary collaborations with behaviour-change specialists, among others.

### 9.5.2 | Interventions

The design and investigation of interventions are underexposed in the dissertation. To realise a sustainable workforce, interventions need to be designed, tested, and their results should be studied. Intervention technologies could play an interesting role in supporting the worker and lowering the relative workload. Currently, an exoskeleton for surgeons, or for physically active workers, is being designed. This exoskeleton is intended to lower the back and neck load of workers. For physically underexposed workers, interventions that increase the amount of physical activity need to be explored. The focus should mainly be on how a long-lasting effect can be created. In addition, it would be interesting to investigate how this can be achieved without interfering with the private life (e.g. offering time to exercise during working hours) (Dutta, et al., 2019; Sui, et al., 2019; Bergman, et al., 2018). This could potentially improve the capacity and the workability of workers in physically demanding occupations, as well as office workers. These interventions need to be explored and the effects investigated.

### 9.5.3 | Data sharing

One of the requirements was that these technologies should help the workers to open a dialogue about workplace improvements (Spook, et al., 2019). The realization of a toolbox and the role of an occupational physician (Chapter 8) are important to fulfil this requirement. The future perspective is the realization of a toolbox that combines multiple sensor and intervention technologies and provides a low-level overarching feedback to the worker. The toolbox analyses the flow of big data and could finally draws conclusions using self-learning decision support systems. This decision support system can combine or summarize information from specific jobs or worker groups instead of individuals to improve the working conditions. The occupational physician could take a role in the protection of the personal data of the workers. This toolbox with workplace health promoting technologies offers a chance to open a dialogue between workers and employers about workplace improvements.

## 9.6 | Limitations

### 9.6.1 | Monitoring physical workload

The main limitation is that the workload of workers during prolonged performance of their job has not yet been investigated. In this dissertation, the focus is on the development and validation of sensor and intervention technologies to monitor balance between workload and capacity. The technologies are not yet implemented for a longer period of time to correct the balance between workload and capacity. Still, this is important to do and based on these results there needs to be additional exploration into how interventions and workplaces can be improved.



### 9.6.2 | Combining work-related aspects

Another limitation is the focus on only three physical aspects: posture and its related back load, energetic workload, and heat stress. To gain a more complete overview, more physical aspects need to be explored and investigated, including musculoskeletal disorders in the knees, neck and shoulders, repetitive movement of small muscles groups such as for moving the wrist, hands and fingers, and effects of lifting and carrying. Additionally, relations between the physical, cognitive, and social work-related aspects of a job have not been explored; cognitive workload and other social aspects are not taken into consideration with these sensor technologies and interventions. Studies in this area would yield interesting information about how they are related and interact with each other, providing opportunities to solve bottlenecks more efficiently.

### 9.6.3 | Motivation

An observed limitation is that workers were not motivated actively to use the sensor and intervention technology. As a result, a wide range of responses of the workers to the use of the technologies was observed. Firstly, there was much diversity in the response to the interventions provided. This was particularly visible when investigating the effect of intervention of the sensor chair (Chapter 2). The subjects reacted differently to the intervening feedback signal, which was a short vibration in the seat. Some workers did improve their behaviour by reacting to the signal, but most did not respond to the signal at all and some responded for only a short period of time. These individual responses and their motivations need to be investigated in more detail (Vaughan-Johnston & Jacobson, 2020; Hermsen, et al., 2016; van der Lei, 2002), need to be taken into account when developing motivational feedback and interventions (Vaughan-Johnston & Jacobson, 2020; Hermsen, et al., 2016; van der Lei, 2002) and would help to improve the worker conscientious autonomy (Chapter 8). Second, most workers understand the advantages of these technologies and would like to use them as soon as possible. However, other workers react with resistance or complete rejection of the technologies. They create the feeling of the worker being monitored by the employer (Choi, et al., 2017; Jacobs, 2019), despite the advantages of these technologies and the worker's desire for such improvements (Spook, et al., 2019). The method of implementation is important for the acceptance of the technology, especially among workers. Workers as well as employers should be informed in an individually stimulating way.

## 9.7 | Lesson learned

### 9.7.1 | Gold standards of references

A major challenge was the selection of a reference method for all newly developed sensor systems. Not all research topics have a gold standard (as discussed in Chapter 2). Even if there is a standard, it is often not the "gold standard", meaning it is not universally accepted (as discussed in Chapters 6 and 7). Moreover, in some cases (Chapters 6 and 7) there is a difference between the clinical and scientific standard, or the gold standards are not always applicable to in real-life working conditions (as in Chapter 2) or rather are impractical or inappropriate (Saurabh, et al., 2014) (as in Chapter 6 and 7). This indicates the urge for alignment.

### 9.7.2 | Accuracy vs usability

Despite the importance of the validity and reliability of systems, these studies revealed that usability and safety are also important success factors. A technology can have a high accuracy but is unusable if it is not applicable in real-life working conditions. For example, despite its high accuracy, the mouth mask cannot be used in the workplace because it hinders communication. The breathing gas-analysing headset that has been developed does not have this drawback. Requirements of accuracy and applicability are difficult to meet in both scenarios. The breath-analysing headset is less accurate than the mouth mask version, but its applicability in real-life situations is much better because it measures in a non-obstructive and safe manner. The challenging part is finding the proper balance of accuracy and usability for each implementation scenario.

### 9.7.3 | Consumer health technologies

The increasing amount of commercially available health technologies is challenging. More devices become available on the market to self-monitor health parameters. Most consumer wearables are not validated (Peake, et al., 2018) and thus are not accurate enough for scientific or medical research. Still, for scientific and medical research, these self-monitoring wearables could be very useful when validated (Patel, et al., 2012). They could be used for remote monitoring of (work) behaviour or the development of health decline or diseases. Depending on the aims and proposes of the technologies, validation is of major importance (Peake, et al., 2018). These consumer health technologies could contribute to behaviour awareness, show trends to the users and provided that they achieve the minimum levels of accuracy, reliability, and usability.

### 9.7.4 | Human sensory system

Another challenging aspect is the human sensory system. Sensor technologies should support the worker but cannot take over the human sensory system. As stated by Christian Lous Lange *"Technology is a useful servant but a dangerous master"* (Lange, 1921). The technologies may not overrule the human sensory system, as experience and feelings and must be used as means to support the workers' performance.

### 9.7.5 | Older vs younger worker

The health problems faced by the older workers in physically demanding occupations will be different compared to those among younger workers. Older workers often experience problems as the result of working from a young age and under physically harsh conditions. In the last 50 years, many working conditions have been majorly (ergonomically) improved, resulting in lower physical workloads. Still, there are major variations in working conditions between companies and jobs. Much can be improved to optimize the workload for the body. However, it should be noted that physically demanding jobs are not necessarily unhealthy. Office workers who are physically underloaded may experience health problems due to inactivity. Sensor technologies should make the workers aware of their behaviour and should support them to find the healthiest balance for them (Wu & Wang, 2002; Kenny, et al., 2008).

### 9.7.6 | Ethics of technologies

Workers need to be able to respond autonomously and voluntarily to the use of workplace health-promoting technologies (Chapter 8). During the design and implementation of these technologies, the focus must not only be on user-centred design, but the ethical agenda also needs to be taken into account. The design and implementation of sensor and intervention technologies raises complex unanswered moral questions. One of them is the responsibility of the employers and other social actors, and how to handle and exercise autonomy at work (Six Dijkstra, et al., 2020). Protecting the privacy and autonomy of workers cannot be seen as stand-alone issues, but as an interplay between these values, the work context, and the responsibilities of the stakeholders. These ethical considerations need to be encountered when developing workplace health-promoting technologies, and awareness of the responsibilities of all stakeholders (including workers, employees, engineers and scientists) requires full attention. Focusing on a contextual conceptualization of the core ethical principles in the design and implementation of technologies helps to avoid compartmentalization, out-of-context generalization, and neglect of identifying responsibilities. Although it is a long iterative process in which all stakeholders need to be included in order to assess all critical ethical issues sufficiently, this process is crucial for achieving the intended goal of a technology.

### 9.7.7 | Interdisciplinary teams

Another lesson learned was the challenging interdisciplinary character of this project. Although the aims and goals were aligned, each discipline had its own experiences, interests, working culture, definitions, and time schedule. In order to optimize progress, it is important to align goals and expectations as detailed and as soon as possible, preferably before the start of any interdisciplinary project. This should be done not only among research disciplines, but with the whole consortium, including any involved companies.

### 9.7.8 | Science vs design

There is a lack of objective monitoring technologies (Netten, et al., 2011; Patel, et al., 2012; Peake, et al., 2018; Maman, et al., 2017; Vandermissen, et al., 2014; Takala, et al., 2010; Kuijper & Frings-Dresen, 2004; Verschoof, et al., 2005; Boa, et al., 2004; Aryal, et al., 2017; Pancardo, et al., 2015; Mazgoaker, et al., 2017). Product design is time-consuming which resulted in less time for scientific research and a lack of time to validate the technologies in operational working environments (TRL7). This would have provided interesting input about the uncontrolled use of these technologies and multiple work-related research topics. This is not only scientifically interesting but would also had provided interesting input about context specific issues and the optimization of the technologies. Finding the balance between science and design is challenge. No science can exist without design, and design has no basis without science (Verkerke, et al., 2013).

### 9.7.9 | Reality of research

Multiple work-related aspects were covered within the SPRINT@Work project (Appendix I). More relations between physical, cognitive, and social work-related aspects could have been explored. Several interdisciplinary collaborations succeeded (de Jong, et al., 2018), as within the sensor chair study (Chapter 2) where Occupational Health investigated user experiences surrounding the implementation of sensor technologies in the workplace (Spook, et al., 2019). A portion of the study attempted to find a relation between sitting (Chapter 2) and typing behaviour as a parameter related to mental fatigue (de Jong, et al., 2018). However, the software was not working correctly during this study and the data was not usable. As is usual in research, unexpected events occur. This is the reality of research and errors such as this occur in every (interdisciplinary) project, and thus should be taken into account in the planning of the project. For this reason, the project requires a flexible and open-minded attitude of the team members.



## 9.8 | Future challenges

### 9.8.1 | Longitudinal studies

In this dissertation, multiple sensor and intervention technologies were designed (and not even all designs have reached this dissertation), explored, and studied. This dissertation stops with the validation in lab or field studies. These technologies are designed to be used to monitor (im)balances between capacity and workload. After validating each system as an objective monitoring device, these technologies can be utilized for research. The bottlenecks discovered from literature and the needs assessment (Spook, et al., 2019) can be further investigated for solutions. An important research topic is investigating how an imbalance between workload and a worker's capacity can be prevented or solved. Therefore, subjects must be monitored in longitudinal repeated measures. Physically active workers could wear the sensor suit, headset, and core thermometer. For office workers the sensor chair and headset could be used. The workload and the internal response to this external load can be monitored and individual differences should be investigated. Based on these outcomes, interventions to adjust the workload or improve the capacity can be explored, and a healthier balance for the worker can be achieved.

### 9.8.2 | Awareness among stakeholders

Along with ethical considerations, awareness among and the responsibility of all stakeholders is a future challenge. In specific situations, stakeholders may not always be aware of the impact or consequences of implementing workplace health-promoting technologies, like in the case of heat stress. The stakeholders are not aware of the consequences due to a lack of knowledge about heat stress. The consequences on the workers' health are less visible in early stages and become much more severe in a later stage. To prevent health declines, workers, employers, and occupational medical staff need to recognize heat stress incidents. Next, it is important to improve the registration of heat stress incidents in the workplace (Willems, et al., 2018). Lastly, information about the diagnosis and the consequences of heat stress needs to be commonly known among all stakeholders. With these preventative measures alongside monitoring technologies, stakeholders should gain awareness of frequent and prolonged exposure to heat and to accept their responsibility in protecting workers.

### 9.8.3 | Personal factors

These sensor and intervention technologies focus on monitoring and optimizing the workload and work conditions. The personal factors (Figure 1.1 of Chapter 1) were not investigated due to the explorative scope of the studies. The balance between work and the private life of workers is a challenging topic. Personal factors such as lifestyle and health influence the capacity and workability of the worker (Wu & Wang, 2002). This results in work and private life becoming intertwined (van Berkel, et al., 2014) and raises ethical questions when considering scientific methods to analyse this relationship. Scientifically, it is relevant to gain a complete overview of the worker's capacity and (work)load (Varianou-Mikellidou, et al., 2019; Wu & Wang, 2002. To restore the balance between capacity and workload, lowering the workload alone might not be a solution. Instead, the worker could adjust their physical activity outside of the workplace, or the worker's capacity could be improved. The capacity could, in some cases, be improved by adjusting the lifestyle to include more exercise, healthier food consumption, and even by limiting alcohol and tobacco intake. Companies can provide incentive to the workers by making the healthy choice an easier choice. This could also influence the lifestyle of the worker's family and thus positively affect more people than directly involved.

### 9.8.5 | Motivational feedback

Every worker has their own character and thus responds uniquely to feedback and motivations. The differences in individual responses are very relevant to investigate and are important to gain a remaining effect (Vaughan-Johnston & Jacobson, 2020). Additionally, the dosage of the intervention needs to be explored (Hermsen, et al., 2016; Delgadillo, et al., 2017). This information will result in knowledge regarding which type of feedback for which workers is effective, motivates the workers, and creates a long-lasting effect (Hermsen, et al., 2016; Hassan, et al., 2019; Burgers, et al., 2015). This personalized feedback should create awareness and motivate the worker to improve their working behaviour.

### 9.8.6 | Meaningful data

To be able to provide feedback, it is important to not just gather and present data but rather to convert it directly into a meaningful output. With an increasing flow of data, there is much information to be explored. This is challenging because combining data and drawing conclusions is still uncharted territory. Self-learning decision support systems were underexposed in this dissertation, although they are essential to combine the signals of the various sensors and derive conclusions regarding the risk factor of each worker, and which intervention can lower this risk. The decision support system will become successful if it supports the worker by making them aware of their behaviour, help the worker to interpret the data available to them and make appropriate decisions, and contributes towards successful implementation and motivation for long-term use (Spook, et al., 2019; Burgers, et al., 2015).



### 9.8.7 | From design to market-ready product

It is important that these workplace health-promoting technologies designed within a scientific context become market-ready products. They should become available so that workers can take advantage of the benefits they can offer. Therefore, collaborations with companies specialized in this field should be sought after. This will increase the quality of the technology and provide opportunities to put this product on the market. Currently, the proof-of-concept of the breathing gas-analysing headset is being improved into a professional prototype. This is being completed via a collaboration with a company specialized in the development of breathing gas-analysers. All designed, validated, and reliable technologies need to be made available for the audience and optimized into a market-ready product.

## 9.9 | Future perspective

The life expectancy is rapidly increasing and the European population of those older than 65 years is expected to be doubled by 2060 (Koolhaas, et al., 2009; Gotmark, et al., 2018). However, the number of expected “healthy” years does not follow the same trend. Therefor in the future, a sustainable and healthy workforce will become even more and more important. More research about healthy ageing needs to be completed so that and technologies can be developed to play a more dominant role in preventing health problems.

In the future, the workplace will become smarter (Papagiannidis & Arikyan, 2020; Edirisinghe, 2019; Bootsman, et al., 2019) with the implementation of automation, internet of things, big data, artificial intelligence, and decision support systems. Mobile and wearable technologies to make humans and their equipment measurable will be critical to maintain a stable workforce and economy. Wearable technologies will be integrated in the workplace and clothing to monitor the workload continuously and in real-time (Lee, et al., 2020; Yang & Ahn, 2019; Bowen, et al., 2019).

For workers in physically demanding occupations, the technologies will focus on lowering the load on the body. Exoskeletons to support the worker and lower the workload will surely play a dominant role within many organizations. For office workers, the main challenge will remain to be achieving a balance between physical and mental load. Physical inactivity will increase and needs to be prevented or compensated for in order to prevent health problems. The 24-hours society will increase the required of technologies for remote working and wearable health promoting technologies. The human-device interaction will become more and more important, as well as the workers ability to act autonomously and the prevention of overstimulation with information.



## 9.10 | Conclusion

This dissertation presented new measuring systems to determine the physical workload of workers and their physiological responses in an objective, non-obstructive, and safe manner. The smart chair was useful for office workers to monitor sitting behaviour in the workplace. The validity of the sensor suit and ANN-based method for measuring working postures, movements and its related mechanical workload for physically demanding occupations was supported. However, the usability requires improvements. The breathing gas-analysing headset to measure internal physiological responses was not yet completely validated, but its potential was supported and indicates opportunities for further professionalization and use in physically demanding occupations. The validity of the wearable, non-invasive core thermometer measuring the internal response was not confirmed but showed potential to predicting core temperature and heat storage as part of a multivariable system. Ultimately, these systems should assist the worker to achieve a balance between workload and the worker's capacity. After final design and validation steps, these sensor technologies are ready to be used to contribute to the realisation of a sustainable workforce.

## References

Altunok, T. & Cakmak, T., 2010. A technology readiness levels (TRLs) calculator software for systems engineering and technology management tool. *Advances in Engineering Software,* 41(5), pp. 769-778.

Andersen, L., Fallentin, N., Thorsen, S. & Holtermann, A., 2016. Physical workload and risk of long-term sickness absence in the general working population and among blue-collar workers: prospective cohort study with register follow-up. *Occup. Environ. Med.,* 73(4), pp. 246-235.

Apykhtin, K., Chaikovsky, I., Yaroslavska, S. & Starynaska, A., 2018. Interrelation of the Level of Fatigue and the Parameters of the Energy Supply of Activity for Medical Workers. *Austin Cardiology,* 3(1), p. 1019.

Arts, K. & Otten, F., 2013. *Stijgende arbeidsparticipatie en minder uittreding bij ouderen, Sociaaleconomische trends 2013,* Den Haag/Heerlen: CBS.

Aryal, A., Ghahramani, A. & Becerik-Gerber, B., 2017. Monitoring fatigue in construction workers using physiological measurements. *Automation in construction,* Volume 82, pp. 154-165.

Bergman, F. et al., 2018. Treadmill workstations in office workers who are overweight or obese: a randomised controlled trial. *The Lancet Public Health,* 3(11), pp. e523-e535.

Boa, J., Mol, E., Visser, B. & Frings-Dresen, M., 2004. The physical demands upon (Dutch) fire-fighters in relation to the maximum acceptable energetic workload. *Ergonomics,* 47(4), pp. 446-460.

Bootsman, R. et al., 2019. Wearable technology for posture monitoring at the workplace. *International Journal of Human-Computer Studies,* Volume 132, pp. 99-111.

Bowen, J., Hinze, A. & Griffiths, C., 2019. Investigating real-time monitoring of fatigue indicators of New Zealand forestry workers. *Accident Analysis & Prevention,* Volume 126, pp. 122-141.

Brouwer, S. et al., 2013. *Duurzame inzetbaarheid van de oudere werknemer: stand van zaken,* Groningen: UMCG.

Burgers, C., Eden, A., van Engelenburg, M. & Buningh, S., 2015. How feedback boosts motivation and play in a brain-training game. *Computers in Human Behaviour,* Volume 48, pp. 94-103.

CBS, 2012. *65-jarigen leven langer zonder beperkingen, maar meer met chronische ziekten.* [Online] Available at: http://www.cbs.nl/nl-NL/menu/themas/gezondheid-welzijn/publicaties/artikelen/archief/2012/2012-3669-wm.htm [Accessed 25 November 2013].

Chaglla, J., Celik, N. & Balanchandran, W., 2018. Measurement of Core Body Temperature Using Graphene Inked Infrared Thermopile Sensor. *Sensors,* 18(10), p. 3315.

Costa-Black, K., Feuerstein, M. & Loisel, P., 2013. Work Disability Models: Past and Present. In: *Handbook of Work Disability: Prevention and Management.* New York, US: Springer Science+Businuess Media, pp. 71-93.

de Jong, M., Bonvanie, A., Jolij, J. & Lorist, M., n.d. Typewriting dynamics during prolonged office work.

de Jong, M., Jolij, J., Pimenta, A. & Lorist, M., 2018. Age Modulates the Effects of Mental Fatigue on Typewriting. *Frontiers in Psychology,* 5(9), p. 1113.

Delgadillo, J. et al., 2017. Improving the efficiency of psychological treatment using outcome feedback technology. *Behaviour Research and Therapy,* Volume 99, pp. 89-97.

Diaz-Piedra, C., Gomzed-Milan, E. & Di Stasi, L., 2019. Nasal skin temperature reveals changes in arousal levels due to time on task: An experimental thermal infrared imaging study. Applied Ergonomics, Volume 81, pp. 102870.

Dutta, N., Walton, T. & Pereira, M., 2019. One-year follow-up of a sit-stand workstation intervention to decrease sedentary time in office workers. *Preventive Medicine Reports,* Volume 13, pp. 277-280.

Edirisinghe, R., 2019. Digital skin of the construction site: Smart sensor technologies towards the future smart construction site. *Engineering, Construction and Architectural Management,* 26(2), pp. 184-223.

Gotmark, F., Cafaro, P. & O'Sullivan, J., 2018. Aging Human Populations: Good for Us, Good for the Earth. *Trends in Ecology & Evolution,* 33(11), pp. 851-862.

Hassan, L., Dias, A. & Hamari, J., 2019. How motivational feedback increases user's benefits and continued use: A study on gamification, quantified-self and social networking. *International Journal of Information Management,* Volume 46, pp. 151-162.

Havenith, G. & Heus, R., 2004. A test battery related to ergonomics of protective clothing. *Applied Ergonomics,* 35(1), pp. 3-20.

Healy, G. et al., 2013. Reducing sitting time of office workers: short-term efficacy of a multicomponent intervention. *Preventive Medicine,* 57(1), pp. 43-48.

Heerkens, Y. et al., 2004. The use of the ICF to describe work related factors influencing the health of employees. *Disability and Rehabilitation,* 26(17), pp. 1060-1066.
Hermsen, S., Frost, J., renes, R. & Kerkhof, P., 2016. Using feedback through digital technology to disrupt and change habitual behaviour: A critical review of current literature. *Computers in Human Behaviour,* Volume 57, pp. 31-74.

Ilmarinen, J., 2001. Aging Workers. *Occupational and environmental medicine,* 58(8), pp. 546-552.

Jacobs, J. et al., 2019. Employee acceptance of wearable technology in the workplace. *Applied Ergonomics,* Volume 78, pp. 148-156.

Johnson, D. & Powers, T., 2005. Computer Systems and Responsibility: A normative look at technological complexity. *Ethics and Information Technology,* 7(2), pp. 99-107.

Kadir, B., Broberg, O. & Souza da Conceicao, C., 2019. Current research and future perspectives on human factors and ergonomics in Industry 4.0. *Computers & Industrial Engineering,* Volume 137, p. 106004.

Kenny, G., Yardely, J., Martineau, L. & Jay, O., 2008. Physical Work Capacity in Older Adults: Implications for the Aging Worker. *American Journal of Industrial Medicine,* Volume 51, pp. 610-625.

Kim, S., 2018. *Prediction of Heat Strain by Heart Rate for Firefighters in Protective Clothing,* Seoul, South Korea: Graduate School of Human Ecology, Seoul National University.

Kirkland, K. & Dobbin, D., 2009. *Healthy Aging for a Sustainable Workforce,* Silverspring, Maryland, United States: MDB Inc..

Koolhaas, W. et al., 2009. *Bevorderen van de arbeidspartcipatie van de oudere werknemer,* Groningen: Universtair Medisch Centrum Groningen.

Kuijper, P. & Frings-Dresen, M., 2004. World at work: Refuse collectors. *Occup Environ Med.,* 61(3), pp. 282-286.

Kuruganti, U., 2019. Sensors for monitoring workplace health. In: *Bioelectronics and Medical Devices; From Materials to Devices - Fabrication, Applications and Reliability.* 978-0-08-102420-1 ed. Cambridge, United Kingdom: Woodhead Publishing, pp. 537-553.

Lange, C., 1921. *Internationalism,* Oslo, Norway: Nobel Institute.

Lee, W., Migliaccio, G., Lin, K. & Seto, E., 2020. Workforce development: understanding task-level job demands-resources, burnout, and performance in unskilled construction workers. *Safety Science,* Volume 123, p. 104577.

Maman, Z., Yazdi, M., Cavuoto, L. & Megahed, F., 2017. A data-driven approach to modeling physical fatigue in the workplace using wearable sensors. *Applied Ergonomics,* Volume 65, pp. 515-529.

Mathiassen, S., 2006. Diversity and variation in biomechnical exposure: What is it, and why would we like to know?. *Applied Ergonomics,* 7(24), pp. 1-11.

Mathiassen, S. & Winkel, J., 1991. Quantifying variation in physical load using exposure-vs-time data. *Ergonomics,* 34(12), pp. 1455-1468.

Mazgoaker, S. et al., 2017. Measuring core body temperature with a non-invasive sensor. *Journal of Thermal Biology,* Volume 66, pp. 17-20.

Netten, M., Doelen, van der,, L. & Goossens, R., 2011. Chair based measurements of sitting behaviour: A field study of sitting postures and sitting time in office work. In: *Digital Human Modeling and Applications in Health, Safety, Ergonomics, and Risk Management. Human Body Modeling and Ergonomics.* Berlin Heidelberg, Germany: Springer, pp. 261-268.

Palm, E., 2009. Securing Privacy at Work: The importance of contextualized consent. *Ethics and Information Technology,* 11(4), pp. 233-241.

Pancardo, P. et al., 2015. Real-Time Personalized Monitoring to Estimate Occupational Heat Stress in Ambient Assisted Working. *Sensors,* 15(7), pp. 16956-16980.

Panel on Musculoskeletal Disorders and the Workplace, Commission on Behavioural and Social Sciences and Education, National Research Council (NRC) and Institute of Medicine (IOM), 2001. Patterns of Evidence. In: *Musculoskeletal disorders and the workplace: Low back and upper extremities.* Wasington DC, US: The National Academic Press, pp. 351-363.

Papagiannidis, S. & Arikyan, D., 2020. Smart offices: A productivity and well-being perspective. *International Journal of Information Management,* Volume In press, p. 102027.

Patel, S., Park, H., Bonato, P., Chan, L., Rodgers, M., 2012. A review of wearable sensors and systems with application in rehabilitation. *Journal of NeuroEngineering and Rehabilitation,* 9(21), pp. 1-17.

Patel, S. et al., 2012. A review of wearable sensors and systems with application in rehabilitation. *Journal of NeuroEngineering and Rehabilitation,* 9(21), pp. 1-17.

Peake, J., Kerr, G. & Sullivan, J., 2018. A Critical Review of Consumer Wearables, Mobile Applications, and Equipment for providing Biofeedback, Monitoring Stress, and Sleep in Physicall Active Populations. *Frontiers in Physiology,* Volume 9, pp. 1-19.

Punt, M., Nematimoez, M., van Dieen, J. & Kingma, I., 2019. Real-time feedback to reduce low-back load in lifting and lowering. *Journal of Biomechanics,* p. 109513.

Rechel, B. et al., 2013. Ageing in the European Union. *The Lancet,* 381(9874), pp. 1312-1322.
Richmond, V., Davey, S., Griggs, K. & Havenith, G., 2015. Prediction of Core Body Temperature from Multiple Variables. *Ann Occup Hyg,* 59(9), pp. 1168-1178.

Saurabh, K., Rao, H., Amrutur, B. & Sundarranjan, A., 2014. Continuous core body temperature estimation via surface temperature measurements using wearable sensors: Is it feasible?. *Biodevices (Conference paper,* pp. 181-186.

Shephard, R., 1997. *Aging, physical activity, and health.* s.l.:0-87322-889-8.

Six-Dijkstra, M.W.M.C., Siebrand, E., Dorrestijn, S., Salomons, E.L., Reneman, M.F., Oosterveld, F.G.J., Soer, R., Gross, D.P. & Bieleman, H.J., 2020. Ethical Considerations of Using Machine Learning for Decision Support in Occupational Health: An Example Involving Periodic Workers' Health Assessments. *Journal of Occupational Rehabilitation*, Volume 30, pp. 343-353.

Spook, S., Koolhaas, W., Bultmann, U. & Brouwer, S., 2019. Implementing sensor technology applications for workplace health promotion: A needs assessment among workers with physically demanding work. *BMC Public Health,* Volume 9, p. 1100.

Spook, S., Koolhaas, W., Bultmann, U. & Brouwer, S., n.d. Implementing sensor technology applications for workplace health promotion: A needs assessment among workers with physically demanding work.

Straub, J., 2015. In search of technology readiness level (TRL) 10. *Aerospace Science and Technology,* Volume 46, pp. 312-320.

Sui, W. et al., 2019. The effects of sedentary behaviour interventions on work-related productivity and performance outcomes in real and simulated office work: A systematic review. *Applied Ergonomics,* Volume 75, pp. 27-73.

Takala, E. et al., 2010. Systematic evaluation of observational methods assessing biomechanical exposures at work. *Sand. Journal of Work Environment Health,* 36(1), pp. 3-24.

Thorp, A. et al., 2012. Prolonged sedentary time and physical activity in workplace and non-work contexts: a cross-study of office, customer service and call centre employees. *International Journal of Behavioural Nutrition and Physical Activity,* 9(129).

Ullrich, C. et al., 2019. Use the Internet of Things for enhanced Support of workers in Manufacturing. In: *Perspectives on Wearable Enhanced Learning (WELL): Current Trends, Research, and Practice.* 978-3-319-64300-7 ed. Switserland: Springer Nature, pp. 143-166.

van Berkel, J. et al., 2014. Ethical considerations of worksite health promotion: an exploration of stakeholders' views. *BMC Public Health,* Volume 14, p. 458.

van der Lei, J., 2002. Information and communication technology in health care: do we need feedback?. *International Journal of Medical Informatics,* 66(1-3), pp. 75-83.

Vandermissen, G., Verhoogen, R., Cauwenbergh, van, A. & Godderis, L., 2014. Determinants of maximal oxygen uptake (VO2 max) in fire fighter testing. *Applied Ergonomics,* 45(4), pp. 1064-1066.

Varianou-Mikellidou, C. et al., 2019. Occupational health and safety management in the context of an ageing workforce. *Safety Science,* Volume 116, pp. 231-244.

Vaughan-Johnston, T. & Jacobson, J., 2020. “Need” personality constructs and preferences for different types of self-relevant feedback. *Personality and Individual Differences,* Volume 154, p. 109671.

Verschoof, S., Kuijer, P. & Frings-Dresen, M., 2005. Does a rolling floor reduce the physical workdemands and workload, and increase the productivity of truckdrivers handling packed goods?. *Applied Ergonomics,* Volume 36, pp. 595-600.

Verkerke, G.J., Houwen, E.B., van der, Broekhuis, A.A., Bursa, J., Catapano, G., McCullagh, P., Mottaghy, K., Niederer, P., Reilly, R., Rogalewicz, V., Segers, P. & Verdonschot, N., 2013. Science versus Design; comparable, contrastive or conducive?. *J Mech Behav Biomed Mat*, Volume 21, pp. 195-201.

Warmelink, H. et al., 2020. Gamification of production and logistics operations: Status quo and future directions. *Journal of Business Research,* Volume 106, pp. 331-340.

Waschull, S., Bokhorst, J., Molleman, E. & Wortmann, J., 2020. Work design in future industrial production: Transforming towards cyber-physical systems. *Computers & Industrial Engineering,* Volume 139, p. 105679.

Weerding, W. et al., 2005. Health problems lead to considerable productivity loss at work among workers with high physical work loads jobs. *Journal of Clinical Epidemology,* Volume 58, pp. 517-523.

Willems, J., Buskens, E., Kamp, C. & Heus, R., 2018. *Gezondheidsmonitoring bij de brandweer,* Arnhem: Brandweer Nederland.

Wu, H. & Wang, M., 2002. Relationship between maximal acceptable work time and physical workload. *Ergonomics,* 45(4), pp. 280-289.

Yang, K. & Ahn, C., 2019. Inferring workplace safety hazards from the spatial patterns of workers’ wearable data. *Advanced Engineering Informatics,* Volume 41, p. 100924.