Sensors@Work

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Summary

Worldwide, the life expectancy and age of retirement are rapidly increasing, resulting in an aging workforce that often experiences a misbalance between work capacity and workload. This will negatively impact the overall well-being, workability, work performance, and safety of workers, eventually incurring high absenteeism or incapacitation costs for companies, the government, and the (working) population throughout the Netherlands and the Western World. To redeem the costs of aging and to maintain a stable workforce and economy, multiple countries have increased the age of retirement. This alone, however, will not be enough to maintain a sustainable and healthy workforce. In *Chapter 1* the focus is on how a sustainable workforce could be created and the needs of both workers and employers. To gain a sustainable workforce and healthy aging working population, a balance between work capacity and workload needs to be achieved. Physically active and office workers experience work-related health problems caused by a lowered capacity due to aging and the high or low physical demands for their jobs. The three main factors that puts workers at risks include a high mechanical workload, an internal energetic workload, and external heat exposure. Sensor technologies are very useful to continuously monitor the workload of workers, but there is a lack of sensor technologies capable of reliably measuring the workload during work without interfering with the workability. Besides, effective interventions that decrease the mismatch between capacity and workload are lacking as well. The objective of this dissertation is to develop and validate sensor technologies to monitor and improve working postures and related mechanical workload, internal energetic workload, and internal reactions to external heat exposure.

In Chapter 2, the mechanical workload of office workers is investigated. A 'smart' office chair can monitor sitting behavior and provide tactile feedback, aiming to improve sitting behavior and to prevent health problems and musculoskeletal discomfort associated with prolonged sitting. In a 12-week prospective cohort study among office workers, the sitting duration, posture, feedback signals, and musculoskeletal discomfort were measured. This study showed that the 'smart' chair was capable of monitoring sitting behavior. The feedback signal, however, led to small or insignificant changes in the sitting behavior of office workers.

In Chapter 3, monitoring the mechanical workload of physically active workers is investigated. With a 'sensor suit,' the working postures of multiple types of workers were

monitored and with an neural network the corresponding moment of the lumbar region was calculated automatically. This study observed that the sensor system showed differences in the physical load exposure of the lumbar region in coherence with perceived intensity levels and character of the work task in physically demanding occupations.

In Chapter 4 and 5 the focus is on an investigation about monitoring the energetic workload. In *Chapter 4* a patent application is presented. A headset, which analyzes breathing gasses to determine energy expenditure was developed and tested. This is the first working headset which can analyze breathing gasses without the need of a mouth mask. Unique aspects of this device include the design of the air catch-up box replacing the mouth mask, the algorithm to calculate the volume of breath flow from the nose or mouth, and the integrated wind sensor and its algorithm to eliminate influences of environmental wind. In *Chapter 5*, the validation and user experience of the proof-of-concept headset prototype is discussed. The headset that monitors the energetic workloads was used for physically active workers and was found to be more valid than heart rate monitoring alone, and more practical than indirect calorimetry with a mouth mask. The subjects preferred the headset over the mouth mask because it was more comfortable, did not hinder communication, and had a lower breathing resistance.

To be able to monitor heat exposure of physically active workers, two wearable thermometers were tested for their reliability and validity. In *Chapter 6* a study of the validity and reliability of a commercial, wearable, and non-invasive core thermometer, Cosinuss°, during firefighting simulation tasks in presented. The core temperatures of firefighters when working in two types of protective clothing was compared. Without calibration, the accuracy of the thermometer was unacceptably low. With individual calibration, the accuracy was acceptable but was decreased when working. In *Chapter 7*, the accuracy of this wearable thermometer was evaluated and its usability explored in both a laboratory setting and in real-life working conditions. It was again concluded that, without a correction factor, the thermometer is inaccurate. With correction, the accuracy of this wearable ear canal thermometer was confirmed during rest, but not in outdoor working conditions or while wearing a helmet or hearing protection. In *Appendix I,* the development and lab-test of an innovative wearable non-invasive core thermometer has been described. This device showed good correlations compared to the infrared thermometry used in hospital settings. However, some unrealistically high values were measured and it showed to have a lower ease of use.

In *Chapter 8,* the ethical considerations behind monitoring the workload of employees are described. The aim of the study was to address challenges by analyzing two ethical issues, privacy and autonomy, of workers, in a real-life research setting. The results show that the protection of privacy and autonomy of workers cannot be seen as stand-alone issues; there is an interplay between these values, the work context, and the responsibilities of workers and their employer. Focusing on a contextual conceptualization of core ethical principles identified during the project helps to avoid compartmentalization, generalization, and neglect of responsibility. Developing context-specific ethics makes it possible to examine the particular implications of a certain value for a specific situation. A practical, adaptive tool for the ethical design and implementation of workplace health promotion technologies and how stakeholders can take their responsibility and support autonomy, is lacking. Engineers and scientists need to consider how the design and implementation of their technologies influence and mold the values of employers and workers and adapt their technologies to increase ethical acceptance. This interplay between design and implementation is underexposed in literature, but it is critical for the success of responsible innovations.

In *Chapter 9,* the sensor technologies and their implementation in the workplace are discussed in terms of an evaluation of the results, the relevance of these developments and proposed future research. With the data obtained from these sensor technologies, the individual physiological response on the workload can be monitored and a misbalance between workload and capacity can be prevented. After final design and validation, these sensor technologies are ready to be used to contribute towards the realization of a sustainable workforce.