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Commentary

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Ethics and Privacy Considerations Before Deploying Sensor Technologies for Exposure Assessment in the Workplace: Results of a Structured Discussion Amongst Dutch Stakeholders

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Abstract

Will sensor-based exposure assessment be the future in workplace settings? Static instruments with embedded sensors are already applied to monitor levels of dangerous substances—in the context of acute health effects—at critical locations. However, with wearable, lightweight, miniaturized (low-cost) sensors developing quickly, much more is possible with sensors in relation to exposure assessment. Sensors can be applied in the work environment, on machines, or on employees and may include sensors that measure chemical exposures, but also sensors or other technologies that collect contextual information to support the exposure measurements. Like every technology it also has downsides. Sensors collect data on individuals that, depending on the purpose, need to be shared with others (e.g. health, safety and environment manager). One can imagine that people are afraid of misuse. To explore possible ethical and privacy issues that may come along with the introduction of sensors in the workplace, we organized a workshop with stakeholders (*n* = 32) to discuss three possible sensor-based scenarios in a structured way around five themes: purpose, efficacy, intrusiveness, proportionality, and fairness. The main conclusion of the discussions was that stakeholders currently see benefits in using sensors for applied targeted studies (short periods, clear reasons). In order to find acceptance for the implementation of sensors, all individuals affected by the sensors or its data need to be involved in the decisions on the purpose and application of sensors. Possible negative side effects need to be discussed and addressed. Continuous sensor-based monitoring of workers currently appears to be a bridge too far for the participants of this workshop.

Keywords: ethical and privacy issues; occupational exposures; sensor-based exposure assessment; sensor-based scenarios; sensors at the workplace; stakeholder consultation workshop

Why apply sensors at the workplace?

For monitoring and management of occupational exposures, exposure measurements are currently performed by taking samples from the breathing zone of workers, while observing and registering the workers activities. The samples are analysed in a laboratory and together with the observations interpreted by industrial hygienists before providing them to the company (BOHS/NVvA, 2011; EN689, 2018). The benefit of this procedure is that a wide range of substances can be monitored with high precision and sensitivity allowing the result being used for quantitative risk assessment. However, this process may take days to weeks, resulting in feedback long after the exposure took place. Such measurements are generally time-integrated over a full working day and as a result ignore the peaks in exposure and variations over time (Goede *et al.*, 2020).

With lightweight, miniaturized, and technically advanced (low-cost) sensors developing quickly, we expect a shift towards sensor-based personal exposure assessment in the future for a wider range of exposures like airborne particles and specific (chemical) substances (AIHA, 2016; National Academy of Sciences, 2017; Morawska *et al.*, 2018; Goede *et al.*, 2020). Especially wearable devices able to provide time-resolved measurement data to the wearer and/or to an on-line platform wirelessly are interesting for this application. These sensors, that differ substantially in their level of maturity, share the common disadvantage that the quantitative output is not yet reliable enough to be used for regulatory purposes. And even though initiatives are being developed (e.g. CEN/TC 137 WG3; CEN/TC 264 WG42), no harmonized and agreed international methods and protocols are available yet for the use of sensors in occupational settings as is the case for traditional sampling technologies. As a consequence, the selection, evaluation, and calibration of sensors for a particular workplace may consume significant efforts (S. Ruiter *et al.*, unpublished data). Nevertheless, we are confident that many of these issues will be solved in the future providing opportunities to use sensor-based exposure assessment in addition to the traditional measurements to benefit from the real-time character and high resolution in time and space as described in more detail by Goede *et al.* (2020). Ultimately, when initial developments with respect to data infrastructure and methods for data interpretation have been completed, sensor measurements will be less labour-intensive and less expensive than traditional exposure assessment. As a consequence, it is expected that the amount of exposure data collected with sensors will be much larger providing better insights in within and between worker exposure variability as well as exposure determinants. This will provide the basis for more data-driven and personalized exposure control strategies.

Ahead of such developments and assuming that wearable sensors provide reliable data for the intended usages, we focussed on the fact that sensors collect data that may reveal (personal) information about a worker. It can be imagined that people are afraid of misuse of such data and that possible ethical and privacy issues are raised. In fact, ethical and privacy aspects of applying sensor technologies are often mentioned as an important restricting issue (Yang *et al.*, 2016; Choi *et al.*, 2017; Schall *et al.*, 2018; Jacobs *et al.*, 2019; Loncar-Turukalo *et al.*, 2019; McAleenan *et al.*, 2019; Merhar *et al.*, 2019). We explored these possible issues in a workshop with stakeholders including employers and employees.

Possible ethical and privacy issues

Ethical and privacy issues are not new with respect to the collection of personal information. In most research and governmental organizations, studies collecting personal (biomedical) information are obliged to perform an ethical risk assessment and present a data management plan, which needs to be approved by a competent body as for example regulated in the Dutch Medical Research Involving Human Subjects Act (WMO, 1998). In addition, in 2016 the General Data Protection Regulation (GDPR, 2016) went into force to protect the privacy of personal data. Studies collecting personal exposure data need to follow these legislations for both, traditional as well as sensor-based measurements. As a consequence, in most cases participants to a study need to sign an informed consent by which the study coordinator is allowed to store the collected data for the agreed periods and under the agreed conditions and use the data for the agreed purposes, which are carefully considered and restricted.

In case of sensor-based measurements possible ethical and privacy aspects depend on the type of application. Sensors can be applied in the work environment, on machines, or on individuals (Fig. 1). The data can be shared only with the specific worker [called *data-object* in General Data Protection Regulation (GDPR)], at the group level and anonymized with others [e.g. health, safety and environment (HSE) manager] or at

Figure 1. Sensors can be applied in the work environment, on machines, or on individuals. Depending on the purpose, the data need to be shared only with the data-object, grouped and anonymized with others or individually and traceable to the data-object with others. In addition, data can be used in real-time only or stored and used retrospectively.

the individual level and traceable to the data-object with others. The purpose of using sensors defines the required level of data sharing. For direct warning applications it is sufficient to share the data only with the data-object. However, if the purpose is to create an exposure registry, the data need to be stored at the individual level and to be traceable to the data-object. And many applications require a level of data sharing somewhere in the middle of these two extremes. Thus, sensors may collect data on individuals and, although not necessarily personal data, one can imagine that workers are afraid of misuse of such data.

Ethical issues arise in situations where important values are at stake. Examples include situations where individuals experience the sensors as 'big brother is watching you' (comfortability/well-being), where individuals are forced to wear sensors and have no freedom of choice (self-determination), where data meant to improve workers health are actually negatively used in appraisal interviews (trust), where alerts when exposure exceeds limit values are visible to everyone (privacy) or where workers become responsible for their own working conditions without supervision of the employer (responsibility) (a.o. Krom *et al.*, 2018; Schall, 2018; Choi, 2017).

Structured discussions around five themes to identify ethical and privacy issues in stakeholder workshop

Based on a Dutch report on the practical and ethical considerations of using biomonitoring and sensoring at the workplace (Krom *et al.*, 2018) and in collaboration with the author we selected five relevant ethical themes to structure the workshop around:

- Purpose: what is the purpose of applying sensors?
- Efficacy: is applying sensors effective for this purpose?
- Intrusiveness: how intrusive is applying sensors and to whom?
- Proportionality: is applying sensors proportional to the purpose?
- Fairness: are the benefits and burdens equally divided over the people involved?

No comparable stakeholder consultation studies were identified, but the selected themes are supported by findings on employee acceptance as e.g. reported by Choi *et al.* (2017) and Jacobs *et al.* (2019) and in line with the considerations of McAleenan *et al.* (2019) based on literature review.

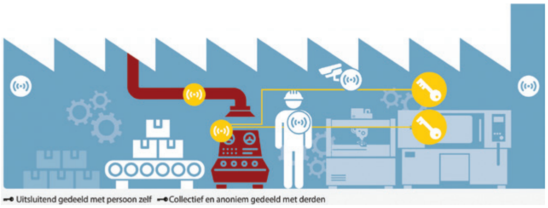
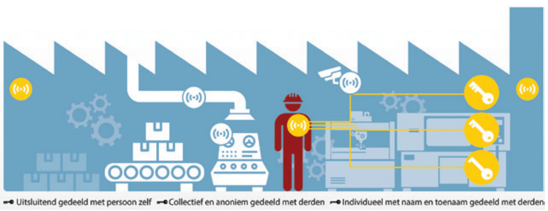
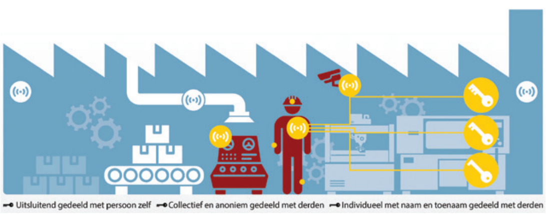
We organized a workshop in the Netherlands with companies (n = 14; both employers and employees), representatives of sector organizations and trade unions (n = 6), consultants and specialists (n = 7), and representatives of governmental organizations (n = 5). We announced the workshop through personal networks of the co-authors and LinkedIn and we accepted all individuals that were interested and who represented these categories, with criteria being a target number of 30 participants and a focus on company representatives.

To inform the participants we provided them with factsheets (Factsheets, 2020) 2 weeks before the workshop in which we described different applications of sensors, pro's and con's and potential ethical issues.

Workshop proceedings

During the workshop participants were presented with three different example scenarios: (i) sensor as detector of high concentrations or of faulty (use of) exposure control measures, (ii) stationary sensor network and linking employees to these concentrations by using indoor location tracking (ILT), and (iii) personal sensors with the option to combine with sensors and technologies to measure context information (Table 1). This latter scenario may need some explication: technically

Table 1. Explanation of the three scenarios discussed during the workshop.

1. Sensor as detector 	Sensors can be applied to enhance the efficacy of control measures or working procedures. The sensors are applied on machines or equipment, not on individuals. Both sensors that measure chemicals as well as sensors measure physical parameters like pressure, distance, temperature, orientation, vibration, etc. may be used for this purpose. Examples are: -Excessive concentrations of emission sources or workplace practices result in ventilation to activate automatically -An alert is given to a worker when the orientation of a spray gun towards a surface is such that the overspray potentially results in high exposure
2. Stationary sensor network with ILT 	Stationary sensors are positioned and distributed throughout the workroom to measure time-resolved chemical concentrations. Based on this data, dynamic space-resolved concentration maps can be modelled. These concentration maps can be used to identify zones with elevated concentrations or to identify locations of sources of potential exposure. If workers are wearing ILT, the data can also be combined with the concentration maps to derive personal exposure profiles.
3. Personal sensor with techniques to measure context 	Personal exposure sensors can be attached to a worker's chest or shoulder. These wearable sensors measure concentrations every few seconds creating a personal exposure profile over the working day. A worker can get access to these results in real-time, e.g. via a phone app. The feedback may be applied to estimate an exposure profile, an 8 h time weighted average or the actual exposure against a threshold value. It is not easy to interpret an exposure profile retrospectively. To understand where the exposure originates from it is necessary to know which activities a worker performed, how these were performed and the circumstances he/she was faced with (*context*). Context can, at least partly, be measured with sensors and other techniques: e.g. ILT, video recordings, and sensors that for example measure a workers' posture, or more simple parameters like movements, vibrations, orientation, or pressure.

it is possible to synchronize sensor data with contextual information from the same resolution, such as ILT systems (Brown *et al.*, 2016), video monitoring and human activity tracking and recognition (NIOSH, 2017; Lun, 2018). Potentially this might replace the need to register observations or log activities manually.

We discussed the three scenarios one after another with the participants, expecting that the possible implications and, as a consequence, concerns/objections would increase from one scenario to the next. After a short introduction, the scenario was discussed with respect to all of the five relevant ethical themes and only then the next scenario was introduced. These discussions were facilitated and supervised by a moderator with a background in ethics.

Feedback from stakeholders

In Table 2, a summary is given per scenario based on the discussions with stakeholders during the workshop and discussed in more detail below. These outputs are not the unanimous group opinions, but rather issues raised that found resonance with a large part of the group. Although different groups of stakeholders were represented, the group was too small to conclude significant differences between different kinds of stakeholders.

An inventory was made with participants to identify the purposes of each application scenario (Table 1). This was followed by a discussion on whether this sensor application would be effective for the purposes. In a similar fashion, each remaining ethical theme (intrusiveness, proportionality, and fairness) was discussed

Table 2. Results of the workshop. Per scenario the results of the structured discussions are presented. In the columns Purpose, Efficacy, Intrusiveness, Proportionality, and Fairness, the discussions are very shortly summarized in key words, reflecting participants opinions.

Purpose	Efficacy	Intrusiveness	Proportionality	Fairness
Scenario 1: sensor as detector				
• Optimization control measure • Shift to higher level STOP[a] principle (occupational hygiene strategy) • Education/training • Indirect: reduce exposure, meet the duty of care	• Different purposes were identified; efficacy can only be judged for a particular situation at the time • Thresholds required for onset sensor-based alert • The sensor technology must be trustworthy • Does not measure personal exposure	• Sensor as detector in principle not intrusive • Not intrusive, but data can be used negatively • Warning signal can be heard by everyone → could be intrusive	• Not very drastic and may be effective, but pay attention to possible drastic side effects (like alert visible to all, or misuse of frequency of alerts for a worker)	• Involve all affected individuals (employees, employers, HSE manager, occupational physician, etc.) in the decision to use sensors
Scenario 2: stationary sensor network possibly in combination with ILT				
• 'No go'-zones/safe walking routes • To make unexpected emissions visible • To find emission sources • Workplace assessment/derive Similar Exposure Groups (SEGs) • In combination with ILT to derive personal exposure	• Many stationary sensors perfectly distributed are required to obtain trusted concentration maps → not easy to achieve • (Dynamic) concentration maps are effective for purposes • In combination with ILT for personal exposures not effective: complex method with uncertain results	• A stationary sensor network not intrusive • The feedback can be intrusive though • ILT very intrusive • Very much depending on who gets access to the data	• The combination of stationary sensors and ILT far too complex technique to derive personal exposures • Better and more simple techniques are available • ILT could be used as context sensor	• Even intrusive techniques may be acceptable if employees agree voluntarily and well informed. But, are employees independent and do they have enough knowledge? • Involvement of works council is required • Discuss with all involved individuals (employees, employers, HSE manager, occupational physician, etc.)
Scenario 3: personal sensors in combination with sensors and technologies to measure context				
• To better understand what causes personal exposures (research)	• In companies/sectors, a lot is already known about causes of exposure • Traditional methods (observations) work fine • Sensor-based exposure assessment creates much data → time consuming	• Employees wearing sensors every day is very intrusive • Acceptable for short periods with a clear purpose • Video images are not acceptable: what is the benefit?; risk of misuse large. *This opinion was explicitly not shared by all.*	• Good instructions are preferred above sensors to correct behaviour leading to unnecessary exposure • Supervision by observation and communication is much appreciated	• Measurements without context are useless (unless used in real time)

[a]Hierarchy of controls: Substitution, Technological measures, Organizational measures, Personal Protective Equipment.

and we obtained feedback for each theme as presented in Table 2.

As expected, the second scenario was judged as being more *intrusive* than the first scenario, with the third being thought of as most intrusive. There was a tendency amongst the participants to appreciate the use of sensors as detector, stationary sensor networks in the work environment and even personal exposure sensors (with preconditions). However, the wearing of sensors by individuals (especially ILT and sensors and technologies to measure context) and the possibility that third parties would see the data or data-induced alerts (or feedback systems for workers), was thought of as intrusive. Stationary and personal video cameras were viewed as the most intrusive. One remarkable issue was raised: when sensors are introduced at the workplace providing more personal information on exposure conditions, workers may start wondering (and worrying) how high their exposures have been up to that point. Like sensor-based feedback itself, it was expected that this sudden start of information by wearing sensors, may be experienced as intrusive.

Whether or not the application of sensors is seen as *proportional* to the purpose appears to be a trade-off between the efficacy of the application and the intrusiveness thereof. Also the availability of other techniques and of reliable data interpretation methods plays a role. For example, the combination of stationary exposure sensors combined with ILT was seen by the participants as a too complex method for the purpose of creating personal exposure profiles. Wearing ILT was considered intrusive for workers (as also reported by Choi, 2017) and a combination with a stationary sensor network (as input for a concentration map) to obtain personal exposure profiles was expected to be less reliable, while much simpler techniques to create personal exposure profiles are available (e.g. a personal exposure sensor).

On the topic of *fairness* basically all participants agreed that all individuals involved in the application and use of sensors should be involved in the decision process to ensure a fair agreement. This is currently already common practice in studies where (biomedical) data are collected from individuals as these individuals need to be informed and agree by signing an informed consent (WMO, 1998).

Participants of the workshop found that the application of sensors would be most beneficial for applied targeted studies; temporary studies with clear objectives. By collecting more (time- and space-resolved) data, analysis of sensor data may lead to a better understanding of causes of personal exposure which can be used for exposure reduction strategies and training. Since these types of studies are for limited time periods and for clear reasons acceptance by all involved is within easier reach than more permanent sensor systems with more varied, potentially less well defined, applications.

The idea of workers wearing sensors continuously and receiving automized feedback (to reduce exposure) was not very much appreciated by (at least part of) the participants. In fact, the traditional methods of observations and communication with workers to influence work practices was very much appreciated. Many participants felt that constant data generation was either not necessary or even threatening. The possible enormous data supply was viewed as a burden rather than as a treasure by them.

Taken together, participants were more critical towards the application of sensors with increasing intrusiveness on employees. A general conclusion of the participants, including the critical participants, was that even if an application of sensors has a drastic impact on people, the application could be acceptable if the efficacy for the purpose is high, all people affected are informed and involved in the decisions and participation is voluntarily. This conclusion largely corresponds to the reported findings on employee acceptance of wearable technology in the workplace (Jacobs *et al.*, 2019).

A remarkable observation was that participants were actually more explicit in their opinion before the discussions than after. Where many participants were either in favour or against application of sensors upon presentation of a scenario, during the discussions it became clear that many more aspects play a role and need to be considered than expected up-front, resulting in less pronounced opinions after the discussions. The structured discussion around the five themes facilitated the process of identifying and sharing insights and was highly appreciated by the participants.

Conclusions and future perspectives

From an exposure assessment standpoint the advantages of sensor-based exposure assessment, complementary to the traditional methods of sampling, giving more detailed insight in exposure profiles and the opportunity to collect more (and real-time) data are obvious. In the future, sensors could be applied on worker level to make effects of workers' behaviour and their exposure levels visible, thereby stimulating a situation of 'worker science'.

In order to study the potential ethical and privacy issues raised by stakeholders we organized a workshop with 32 participants consisting of representatives of companies, sector organizations and trade unions, governmental organizations and consultants and specialists. Three sensor-based scenarios were discussed. The discussions were structured around five ethical themes and demonstrated that this stakeholder group was quite critical towards sensor application at the workplace but also brought us interesting insights on the purposes and criteria required to apply sensors in the workplace.

Our workshop was a first initiative to explore ethical and privacy issues with stakeholders in the Netherlands. Even though many stakeholder groups were represented, the sample size did not permit us to obtain insights in different opinions between these groups. In addition, the average age of the participants was relatively high. The same exercise with younger participants that grew up in a more data-rich society may yield the different results. Also, this topic was very new in the domain of occupational hygiene. Occupational hygiene is organized based on many existing procedures and practices relying on traditional exposure assessment techniques that have been around for decades. Sensor technology is disruptive in this field and all stakeholders possibly need time to experiment with these new techniques to explore and embrace its possibilities and get familiar with more data-rich approaches.

Nevertheless, the results of this workshop emphasize the need to take stakeholder considerations into account in all technical and scientific developments. For example, the data infrastructures should be designed in such a way that concerns raised about possible misuse of data are controlled inherently, e.g. by using the privacy-by-design concept following the GDPR regulations. Further exploration of how and under which (pre)conditions personal exposure data may be shared with third parties like an HSE manager, medical officer, or (for example) sector organizations needs to take place. Also, ways to overcome the ethical and privacy problems that people may experience from sensors and technologies that measure contextual information need to be explored again respecting the regulations on ethics (e.g. Dutch WMO) and privacy (GDPR). It is very clear that although very informative, stakeholders may be very reluctant to use, in particular, video images. New techniques need to be explored to use the benefits of video imaging without individuals being recognized or traced from these data files. Also, the ways of providing feedback in relation to the purpose of the sensor application (alert, app, dashboard, etc.) need to be further discussed and developed in collaboration with stakeholders.

Fortunately, the workshop indicated that stakeholders are open-minded to apply sensors for applied research applications. It is up to us as researchers to demonstrate the benefits of using sensor-based exposure assessment and to demonstrate that ethical and privacy issues are taken seriously and can be prevented by technical and organizational means.

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Conflict of interest

The authors declare no conflict of interest relating to the material presented in this article. Its contents, including any opinions and/or conclusions expressed, are solely those of the authors.

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