MONITORING TECHNOLOGY: THE 21ST CENTURY'S PURSUIT OF WELL-BEING?

Introduction

What kind of monitoring technology has made you feel better? Did it have that effect in the long run? Was it perhaps the software that forced you to take a break or the step counter that notified you of your lack of movement? Or was it the professional chat tool through which you could keep in contact with your colleagues? Are these just gadgets or more? If more, can they help us in our pursuit of well-being?

This article will answer the questions just posed. We start with explaining what monitoring technology, well-being and monitoring technology for well-being are. Subsequently, the invasion of traditional occupational electronic performance monitoring (EPM) and information and communication technology (ICT) in the workplace are discussed and compared with monitoring technology for well-being. Derived from this analysis, five main challenges are identified, which have to vanish or be vanquished for monitoring technology for well-being to become mature. We close this article with a concise conclusion.

Monitoring technology

With a smartphone in our pocket, a sports watch around our wrist and the cloud storing our data, we have landed in the age of monitoring. More so than we are even aware; many claim that monitoring technology improves our health and well-being. However, what is monitoring technology really?

Strictly considered, monitoring technology systematically observes, keeps an eye on, or oversees and checks the progress or quality of something or someone over a period of time, based on a sensor or a set of sensors (e.g. sensing audio, vision, location and biosignals). In regard to people, monitoring technology, or lifestyle or behavioural monitoring as it is sometimes called, forms a sub-set within a wider and more general model of remote technology as in telecare and security.

Sensors are installed on or in people and in their environments, and they provide data from which their physiological state and behaviour can be derived. Often, normal physiological states and behaviour are distinguished from the unusual. In the unusual, we should at least distinguish between sudden anomalies (a heart attack or a fall) and gradual changes (e.g. slowly increasing stress levels).

Monitoring technology can take several shapes, which can be roughly characterised using the modalities used:

- audio based (e.g. automatic speech recognition);
- biosignals (e.g. electrocardiogram);
- vision based (e.g. facial expressions);
- text (e.g. Twitter messages);
- blood samples (e.g. hormone levels);
- interaction based (e.g. mouse and keyboard interaction, pressure sensors, global positioning system (GPS));
- questionnaires (e.g. using 5-point Likert scales); and
- interviews (e.g. using a chat bot).

Combinations of these are surprisingly rarely applied. The collection or capturing of such (big) data, however, is only part of the equation. Most likely, it is actually the simplest part. Subsequently, storage, sharing and analysis are needed. Of the latter, in particular, analysis itself already embodies a complex processing pipeline. Additionally, searching the data for patterns and decision support are often needed or at least preferred.

Well-being

What is subjective or psychological well-being, also known as happiness, really? It includes a wide range of aspects, such as life satisfaction, hedonic balance and fulfilment. At the core of well-being is the affective and cognitive evaluation of one's life. It extends from the specific and concrete to the global and abstract: momentary experiences versus people's global judgments about their entire lives. This all makes subjective well-being an extremely difficult concept to capture. Are people able to identify the critical signals themselves? If so, do we know how to process these signals in a meaningful way? Can we bridge this semantic gap, from low-level signals to high-level psychological constructs? Perhaps some people do a better job than others; however, available evidence is, at best, brittle.

A decade ago, Cary L. Cooper (2007) asked our attention for one of our well-being's biggest threats: stress. He stated: 'We're talking now I think about the 21st century black plague. I see stress as the main source of disease or the trigger for disease in the 21st century developed world' (ABC Catalyst) Last year, Bartol (2016) expressed this concern as follows: 'We all experience challenges and stress from relationships, financial problems, work, or past traumas. Although we may not perceive ourselves as ill, stress can weaken our immune system, cause us to overeat, and lead to hypertension, heart disease, or other illness. The health care recreation would treat the causes, our response to stress, our feelings of self-worth, lifestyle, and relationships rather than simply treating the symptoms once illness or disease manifest.'

Can monitoring technologies reduce our stress? Can they improve our well-being? Where are the statistics to back up this claim? Do we need such statistics at all? Even without them, monitoring technology's potential is largely undisputed. Then, what exactly is monitored? Both industry and science claim that wearables can monitor our lifestyle, our stress level and even our sleep quality, to mention just a few. Most surprisingly, they claim to unveil all these things with similar sets of sensors. So the magic must be in the algorithms that process the sensors' signals, in making sense of them.

Monitoring technology for well-being

If it is already hard for people to sense other people's well-being, and obtain and maintain a high level of well-being themselves, how can monitoring technology do this for us? Such technology has to be programmed to do what we cannot do ourselves. Is it nevertheless worth pursuing the attempt to monitor well-being? Yes! Also, its potential should not be underestimated. It can help us, be it consciously or unconsciously, in a wide variety of ways, including monitoring:

- long-term physical well-being (e.g. cardiovascular issues and our immune system);
- physiological reactions (e.g. as present in communication);
- cognitive processes (e.g. perceiving, memory and reasoning); and
- behaviour (e.g. facial expressions, speech, movements and touch).

Therefore, it can monitor our well-being. Thus, it can aid significantly in:

- continuous (semi-)automatic medical check-ups and support for well-being (these should become part of common health care);
- extending healthy people's well-being (this could reduce health care costs significantly); and
- preventing the stress-related diseases that are rapidly becoming the dominant class of illness.

In other words, it can help us to understand and take care of ourselves.

All this illustrates the complexity of monitoring well-being, which primarily lies in:

- its need for a holistic approach, whereas science's and engineering's current knowledge and practice are dispersed;
- the fragile theoretical frameworks from medicine (including, for example, physiology and neuroscience) and psychology it has to rely on – some steps have been made, but many more are needed; and
- handling the incredible, continuous variance in an unknown number of dimensions, which characterises our world.

Fortunately, occupational stress (including workload) was already studied extensively in the 20th century. That work provides a solid base for understanding and computing the mechanisms that underlie stress. It also provides a relatively solid theoretical framework, which has already provided promising results. When brought down to a specific context, a specific goal such as “monitoring of occupational stress”, monitoring technology can already fulfil its promises within a much shorter time window.

Of all channels that can be monitored, biosignals seem to be the most promising to tackle the challenges ahead. This is hardly a surprise, given William James' notion that humans are ‘psycho-neuro-physical mechanisms’ (1893); humans both send and perceive biosignals that can be captured. These biosignals can be used to reveal a range of characteristics of people, including well-being. However, these signals also suffer from noise, and the biosensors often need to be directly connected to the user's skin to guarantee a good signal-to-noise ratio. Nevertheless, they can be measured by non-invasive, relatively unobtrusive sensors (e.g. in sport watches that measure heart rate), making them suited for everyday usage. Moreover, they have the additional advantage of being free from social masking, as you can mask your grief with a smile, but you cannot control your muscle tension or heart rate.

All in all, biosensors are sensitive to noise, but, in that respect, they are not different from other channels (e.g. audio, visual and even text), although the origin of the noise is different. All channels suffer from differences both between people (e.g. in personality) and within people's behaviour (e.g. from day to day). Last night's party, today's discussions at work and last night's sleep interruptions due to the baby crying all influence our monitored well-being in one way or another.

Biosignals can be conveniently obtained via emerging unobtrusive and wearable technologies, including:

- unobtrusive sensing methods;
- smart textile technology; and
- flexible, stretchable and printable electronics.

These provide a rich pallette of sensors and allow advanced biosignal processing.

Amplifiers, filters and dedicated embedded chips for signal (pre)processing can be an integral part of monitoring technology, making it highly efficient. However, of course, all of this has its price. Furthermore, here, it is not a problem, as now even basic smartphones have sufficient computing power to (pre)process the obtained signals in real time. If more computing power is needed, ‘the cloud’ can provide it. We do face limitations in both reliable WiFi transmission speed and smartphones' battery life, but these are the easiest challenges to deal with. The main challenge lies in the sense making. What are the data telling us? Are we stressed? Do we have cardiovascular problems? Are we getting the flu? Are we hungry or agitated or are our environmental circumstances not comfortable? Everything can and will cause changes in the signals we transmit and, consequently, in the signals that will be monitored.

There is already a range of apps that interface with monitoring technology, such as providing limited next-generation medical check-ups. Examples include e-coaches that support you while you are sleeping, running and eating to reduce diabetics. However, many of these apps use no or only basic biosensors and often lack solid clinical validation. So there is a world to win for unobtrusive monitoring technologies, when they are shown to result in reliable signal acquisition and, subsequently, in reliable analysis.

Early electronic performance monitoring at work

Decades ago, industry had already embraced monitoring technologies to control both workers and machines, when man was almost considered to be a specific type of machine. This type of monitoring is often named EPM. These technologies monitor performance, not well-being. The reported advantages of EPM have been many, including how it:

- helps identify training needs;
- facilitates goal setting;
- can lead to productivity gains;

- facilitates telecommuting and 'flex hours';
- assists in resource planning;
- enhances the value of investments in computer systems;
- can provide immediate and objective feedback; and
- reduces bias in performance evaluations.

However, in parallel, EPM has been associated with a number of disadvantages, including how it:

- can be an invasion of privacy;
- increases stress and possible negative long-term health outcomes;
- can lower satisfaction and morale;
- may reduce contact between employees and supervisor;
- may reduce contact between employees and coworkers;
- can lead to focus on work quantity while sacrificing quality;
- can transform the work climate into an 'electronic sweatshop'; and
- may overwhelm the supervisor with data and feedback expectations.

Most of both the advantages and the disadvantages also apply to monitoring technology for well-being.

As a monitoring technology, the implementation of EPM is potentially beneficial for both employer and employee. However, where EPM was originally used to maximise production, the aims of using EPM should be extended to the general well-being of all stakeholders. In the long run, this will also lead to a maximisation of production.

The invasion of ICT at work

Monitoring technology is a type of dedicated ICT, with its pros and cons. Despite its limitations, few people question its potential. However, monitoring technology, like all ICT, has its downsides as well. This section addresses some of the risks of using ICT, such as monitoring technology, at work.

Even before the age of smartphones and tablets, ICT at work already caused health problems. Throughout the decades since then, ICT use at work has intensified with the use of laptops, tablets, smartphones and even wearables (e.g. smart watches). The initial health problems identified were mainly physical, including:

- musculoskeletal problems, including repetitive strain injury (RSI);
- vision problems;
- headache;
- obesity (e.g. as a result of a lack of physical activity);
- stress disorders (e.g. burnout).

More recently, just as many ICT-related problems regarding subjective well-being have been identified as there were problems with physical well-being. Consequently, the original list has been extended to include five additional ICT-related health problems:

- metabolic issues, such as vitamin deficiencies and diabetes;
- addiction (e.g. to games, social media and the Internet);
- sleeping problems;
- social isolation; and
- an unrealistic world view (resulting in depression, for example).

The original list, which was created 25 years ago, had only six entries, of which stress disorders were the only problem directly related to subjective well-being. Nowadays the list contains as many health problems with physical well-being as with subjective well-being.

With the rapid progress in ICT, it has leaped from work to our homes. Consequently, the extended list concerns general health issues, not necessarily merely occupational health issues. However, the traditionally strict separation between private life and work life is dissolving, as they blend more and more, at least for knowledge workers. The omnipresent Internet and the many other ICT advances have pushed flexible work to become the new standard, providing workers with both freedom and constant work pressure in parallel.

This brings us to the following questions: will monitoring technology add to the list of problems mentioned here? Or will it be distinct from other ICT and instead help solve the problems caused by ICT? If the latter, monitoring ICT would prevent or cure problems caused by general ICT. Perhaps this is possible if monitoring technology is truly human-centered and work-centered.

Challenges for monitoring well-being at work

Will monitoring technology for well-being become the worker's best friend? In solving this challenge, monitoring technology relies on clinical experience of conducting experiments, interventions and scalable approaches. Indeed, it has frequently been claimed that all ICT-related occupational problems have been solved using monitoring technology. For example, musculoskeletal problems can be prevented using persuasive technology, the problem of physical inactivity is approached similarly and so are headaches, diabetes, sleeping problems and social isolation. So it seems to be a case of 'one size fits all'. However, many solutions prove to be fragile and random control trails are absent or conducted at a small scale. Also, solutions are at the level of gadgets instead of at the level of targeted clinical solutions. The problem lies in the increasing tendency to see only what the computer shows. Perhaps this is why monitoring well-being at work has hardly become standard practice. The apps that force you to take a break are intended for the worker's well-being but they do not monitor anything.

Sense making[1]

The speed and ease of computation, statistics and even machine learning have tempted investigators to torture the data until they confess, simply by calculating all possible comparisons for analysis. Hypotheses and even theoretical frameworks are adapted and, moreover, the multiple testing induces flawed conclusions. Consequently, more than ever, scientific results should be handled with the utmost care. Never has the need for replication been so great, as 'we cannot browse over the field of nature like cows at pasture' (Medawar, 1969). Regrettably, in the search for new scientific and business opportunities, many of the monitoring technologies also seem to stem from this practice.[1]

Monitoring technology requires making processes explicit, as otherwise they cannot be programmed and executed as a software package or app linked to some sensors. When aiming to implement theoretical frameworks related to well-being, one is confronted with a lack of proper specified models, and programming becomes difficult. Given this, monitoring technology can also be a method to validate well-being theories, among many others. Moreover, when theoretical frameworks are properly defined, monitoring allows them to be tested in the real world, far outside controlled lab environments. Then we are confronted with life's incredible variability. Often, in human sciences, such variability is averaged out using advanced statistics. However, what to do if it has to work for each individual? Then, even subtle differences can be important. When applied properly, ICT can provide solutions with its machine learning and pattern recognition branches.

Security

In principle, we can assume that monitoring technology data can be stored for ever, if needed. Would the cloud be an option for that or would the data need to be stored locally, in a house, in something wearable or in a person's body? One way or another, wireless transmission seems close to unavoidable. Regrettably, by definition, this introduces a security risk.

[1] Well-executed sense making, with actuators applied (for example, giving tactile feedback), requires to take into account the worker's channel capacity, both for high-level information (for example, Internet search results) and for low-level signals (for example, the sounds of a cash register). High-level information needs to map to the worker's interests and background (van der Sluis et al., 2014). Low-level signals need to take into account the worker's signal-processing capacity, including barely noticeable differences between signals, memorability of sequences and coping strategies (Goldstein and Brockmole, 2017). In all cases, preferably, a personally determined channel capacity is used.

Algorithms that deteriorate data over time have been developed, assuming that older data that have not been accessed in a long time and are only weakly related to current data and processes are not of importance any more. However, how can such algorithms make the correct choices, as (again) even people themselves have a hard time doing this? Is history not something we should cherish, and try to understand, as events and processes seem to recur over time and over generations?

A combination of security measures could reduce the security risk significantly. For example, novel types of biometrics could be utilised for this purpose; in particular, when biosignals have already been recorded, they can serve a dual purpose. However, also with regard to security, much work needs to be done.

Big Brother as stressor

Monitoring technologies require data storage, data processing, data analysis and so forth. Most likely, when data concern our well-being, they are very personal and not meant to be shared with everyone. This becomes a particular problem when multiple monitoring technologies are combined — such as GPS, biosignals and audio — as together they can reveal much more about us than separately.

Managers can use several types of monitoring technology: 'Some of the most commonly used are computer monitoring, which can measure employee keystroke speed and accuracy; video surveillance, which detects employee theft, horseplay, and safety; spying, which uses detective techniques, when there is suspicious activity within the workplace; eavesdropping and phone tapping, which track incoming, outgoing, and the frequency of employee phone calls; and the active badge system, which tracks an employee's location within the workplace' (Mishra and Crampton, 1998). Meanwhile this can be extended by tracking all signals via ICT devices, such as smartphones, tablets and laptops. This applies not only to keystrokes; complete texts can also be captured. Audio surveillance is an obvious extension and so are position tracking (e.g. using GPS) and biosignals.

As with EPM, the worker can perceive monitoring technology for well-being as an invasion of privacy, which is generally experienced to be a stressor. This perception is justified, so, when monitoring technology for well-being is implemented, workers should get full control over their personal data. Consequently, they can choose what data to share. This feeling of control can reduce or even remove the feeling of invasion of privacy. But how many people can even grasp what their data are used for, what they are telling about them and whether or not they can be distributed further?

The employer can try to persuade the worker to provide more information. However, information needs to be placed in context (e.g. the worker's personal circumstances) before proper sense making can be applied. Most likely, this will require at least some human intervention, as context is very hard to grasp and interpret. In any case, the employer needs to be trained in the process of sense making, using the data provided by the monitoring technology, as the employer will be held responsible for the measures taken based on the information.

Embedded and wearable monitoring technology

Not only subjective well-being can be monitored — physical well-being can, too. However, on many occasions, it will be hard to untangle the two. For example, when a biosensor for electrodermal activity is used, sweat secretion is monitored. However, is someone sweating because they have a fever, are stressed or have just walked up the stairs? In controlled lab environments, this can be determined; in the uncontrolled, real world, with its infinite variations, this is very hard, if possible at all. Nevertheless, monitoring technology can provide some safety. Monitoring technology can be and is already used to reduce costs.

- In butcheries, accidents still occur despite the use of professional knives. Workers simply forget that they have the knife in their hand when going to the bathroom or when they get into a conversation. Simple location-based tracking could be used to monitor the location of knives and could provide a signal when a knife is taken outside the restricted area.
- Knowledge workers could benefit from a squeeze mouse that senses their stress. Such a mouse can use pressure sensors and biosensors to determine the stress level. By triangulation

of the signals, a rather robust indicator of stress can be obtained. Feedback can be provided to the worker, the employer, colleagues or all.

- In elderly care, several sensors are used to determine elderly people's safety. These sensors include cameras and microphones. These are used as the caregiver's remote ears and eyes. This way, a caregiver can monitor several elderly people at the same time. General policy is that the elderly person is in control of when their monitor technology is on and when it is off. However, this requires the person to be able to make such a decision.
- An example of invasive monitor technology that is used in daily practice to keep people functioning is an implantable cardioverter defibrillator (ICD). An ICD is a small device that is placed in the chest or abdomen and which can automatically correct for arrhythmias (i.e. irregular heartbeats), using an electric shock to restore the normal heart beat. Modern ICDs also function as pacemakers and defibrillators, although ICD are much more complex.
- Law enforcement personnel (e.g. police officers) can wear cameras, including microphones. These record the officer's conduct when working. If evaluation is needed, the camera recordings can be consulted by both the officer and the employer, enabling both control and feedback on his or her conduct. Currently, this can be done only offline, afterwards. However, in the near future it is, at least technically, possible to do the same online in real time.

Par excellence, this handful of examples illustrates the use and broad application of embedded and wearable monitoring technology. Obviously, many more examples could have been provided. Most important is that the added value of the monitoring technology is clearly defined, including working conditions and access to data, as well as many other aspects, as discussed.

Persuasive (monitoring) technology

Even when all challenges just mentioned are met, monitoring technology can still fail, as none of these aspects guarantee a long-term change in behaviour, which is required when aiming at a high(er) level of well-being. However, via a solution that takes monitoring technology as part of its equation, persuasive technology, it is likely that this aim can be satisfied. Persuasive technology is designed to let users voluntarily change their attitudes or behaviour through persuasion and social influence. In addition to monitoring technology, persuasive technology uses an influencing algorithm and actuators to provide active feedback to the user. Such feedback can be a change of environmental light, different music, an encouraging message or an anonymous comparison with a reference (e.g. peers).

Since Fogg's seminal work in 2002, persuasive technology has obtained a position on the border of social sciences and engineering. However, persuasive technology's stakes are high. Persuasive strategies are hard to invent and apply but, when achieved, they are very successful. The single reason for this is that persuasive technology does not apply coercion, so the worker is self-motivated to change their attitudes and behaviours. Especially when changes have to be maintained in the long run, strong intrinsic motivation is crucial. Alternatively, automated processes can be changed, possibly without the worker's complete awareness, and subsequently fixed, replacing old processes.

Persuasive technology has already shown itself to be successful in health behaviour change. So, why not in occupational settings, in particular when targeting workers' subjective well-being? Well, although many successes are claimed, persuasive technology suffers from several limitations, including (Orji and Moffatt, in press):

- lack of objective evaluation standards;
- fragile integration of behaviour theories and practice in their design;
- the use of multiple strategies within one design, with unidentified relations between the strategies and successes and failures;
- very little longitudinal evaluations of the persuasive technology's effectiveness; and
- no representative target audiences in their design.

Taken together, persuasive technology is not yet a mature branch of science. Consequently, it cannot be expected to be applied in practice in the near future. Nevertheless, it is a promising branch of interdisciplinary science, highly relevant to monitoring technology for well-being at the workplace.

Where do we stand?

The handful of challenges just outlined is by no means an exhaustive list; however, they are five challenges that are among the most important. These challenges need to be vanquished for monitoring technology for well-being in occupational settings in general to become mature. However, for specific occupations, in specific contexts, the current state-of-the-art monitoring technology can already make a significant difference in workers' well-being, as is indicated in the examples described.

Some challenges mentioned will possibly fade away, as society and ICT use will change and, consequently, workers' views on issues such as security and privacy will change. Moreover, developments in embedded and wearable monitoring technology will undoubtedly accelerate and the technology will become more accessible as it rapidly becomes cheaper. This leaves us with the two biggest and related challenges in sense making and persuasive technology. The core challenge is the interpretation of what is monitored and, subsequently, the choice of appropriate actions to take. This is a social sciences (e.g. psychology and communication sciences) challenge instead of a technical challenge. The challenge is in how well we understand our workers, their occupation, their working environment and, simply, their whole lives.

Conclusion

Our well-being and the monitoring of it is a trending, highly complex field of science and practice. Indisputably, monitoring technology will be part of our future; in particular, biosensors will quickly become more common and more important. However, for now, it seems wise to reconsider its foundations. Monitoring technology not only has the potential to increase our well-being; it can also help us understand it. Therefore, its implications are even broader than already anticipated. Moreover, monitoring technology is not limited to aiding our well-being; it can do much more, including increasing our safety.

Monitoring technology started with EPM, which focused on increasing the effectiveness and efficiency of production. EPM has already showed its advantages and disadvantages, as has ICT in the workplace in general. Recently, the list of disadvantages of ICT has doubled, which emphasises the downside to technology. Monitoring technology for well-being at work is facing its own challenges. On the one hand, some can be expected to either vanish (e.g. privacy and security) or be vanquished (i.e. issues with embedded and wearable technology). On the other hand, the challenges in sense making and the inclusion of monitoring technology in persuasive technology can be expected to remain major challenges for a considerable time. Nevertheless, as illustrated, for specific occupations and in specific contexts, monitoring technology can already increase workers' well-being.

In sum, as with all technology that interacts with people, above all, monitoring technology for well-being has to be human centred. Specific implementations for occupational contexts, respecting privacy, security and worker's monitoring stress, exist and more can be expected to follow. Monitoring technology for well-being at large will remain a huge challenge for quite some time; social sciences, instead of science and engineering, should provide the significant solutions. Taking this all into account, monitoring technology for well-being is already a game changer in workplaces and will become even more of one in the future.

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