Monitoring technology: The 21st century's pursuit for well-being?

Egon L. van den Broek

Human-Centered Computing Consultancy, The Hague, The Netherlands

http://www.human-centeredcomputing.com/

Introduction

What kind of monitoring technology has made you feel better? Did it also 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 your lack of movement? Or was it the professional chat tool to keep in contact with your colleagues? Are these gadgets or more? And, 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 is. Subsequently, traditional occupational Electronic Performance Monitoring (EPM) and ICT's invasion 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 than we are even aware, many claim that monitoring technology improve our health and well-being. However, what is monitoring technology really?

Strictly considered, monitoring technology systematically observes, keeps an eye on, or surveils 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). When related to people, monitoring technology, or as it is sometimes called lifestyle or behavioral monitoring, forms a sub-set within a wider and more general model of remote or telecare. Sensors are installed on or in people and in their environments, providing data from which their physiological state and behavior can be derived. Often normal physiological states and behavior are distinguished from the unusual. In the unusual, we should at least distinguish between sudden anomalies (e.g., 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 characterized 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, GPS);
- questionnaires (e.g., using 5-point Likert scales); and

- interviews (e.g., using a chat bot),

where combinations of these are surprisingly rarely applied. The collection/capturing of such (big) data, however, is only part of the equation. Most likely, it is even the simplest part. Subsequently, storage, sharing, and analysis is needed. Of the latter triplet, 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. Well-being's core 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 themselves able to identify the critical signals? And 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; but, available evidence is, at best, brittle ...

A decade ago, Cary L. Cooper (2007) asked our attention for one of our well-being's biggest treats: 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.*''. 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 the sense making.

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! And 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
- behavior (e.g., facial expressions, speech, movements, and touch).

So, it can monitor our well-being. As such, it can aid significantly in:

- continuous (semi-)automatic medical check-ups and support for well-being should become part of common health care;
- extending healthy people's well-being, which 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.

If anything, all this illustrates the complexity of monitoring well-being, which primarily lays in:

- its need for a holistic approach, where science's and engineering's current knowledge and practice are scattered;
- the fragile theoretical frameworks from medicine (e.g., incl. 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 characterizes our world.

Fortunately, occupational stress (incl. workload) has already been studied extensively in the last century and provides a solid base for understanding and computation of the mechanisms underlying stress. This also provided a relative solid theoretical framework, which already provided promising results. When brought down to a specific context, with such a specific goal: monitoring occupational stress, monitoring technology can already redeem 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, taking William James' notion that humans are *psycho-neuro-physical mechanisms* (1893), who 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, also these signals 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., as sport watches do for your heart rate), making them suited for everyday usage. Moreover, they have the additional advantage that they are free from social masking, as you can mask your grief with a smile; but, cannot control your muscle tension of heart rate.

Taking all together, also 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 among people (e.g., in personality) and within people's behavior (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 or the other way.

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

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

which provide a rich pallet of sensors, allowing 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. Also,

here, no problem, as nowadays, even basic smartphones have sufficient computing power to (pre)process the obtained signals real time. And in case of more computing power needed, ``the cloud'' can provide it. But, we will also be facing limitations in both reliable WiFi transmission speed and smartphone's battery life. However, these are the easiest among the challenges. The main challenge lays in the sense making. What is the data telling us? Do we have stress? Are there cardiovascular problems? Are we getting the flu? Are we hungry, agitated, or are environmental circumstances not comfortable? All can and will cause changes in the signals we transmit, in the signals that will be monitored.

A range of apps already exists that interface with monitoring technology, as such providing limited next-generation medical check-ups. Examples include e-coaches that support you while sleeping, running, and eating to reduce diabetics. However, many of these apps use no or only basic biosensors and not seldomly lack a solid clinical validation. So, there is a world to win for unobtrusive monitoring technologies, when shown to result in reliable signal acquisition and, subsequent, analysis.

Early Electronic Performance Monitoring at work

Industry embraced monitoring technologies already decades ago to both control their men and machines, where man was almost considered to be a specific type of machine. This type of monitoring is often named Electronic Performance Monitoring (EPM). So, it is on performance, not well-being. EPM's reported advantages have been many, including:

- Helps identify training needs
- Facilitates goal setting
- Can lead to productivity gains
- Facilitates telecommuting and "flex hours"
- Assists in resource planning
- Enhances value of investment in computer systems
- Can provide immediate, objective feedback
- Reduces bias in performance evaluations

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

- 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 work climate into "electronic sweatshop"
- May overwhelm supervisor with data and feedback expectations

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

The invasion of ICT at work

Even before the age of smartphones and tablets, ICT at work already caused health problems. Throughout the decades that elapsed, 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 RSI;
- vision problems;
- headache;
- obesity (e.g., due a lack of physical activity);
- stress disorders (e.g., burn out);

Although the attention for musculoskeletal problems, in particular RSI seems to be reduced, the problem has not disappeared. Musculoskeletal problems have become more prominent with young people who grow up using smartphones and tablets many hours a day. Vision problems and headache are among the traditional problems and seem, as such, almost accepted. The problem of a lack of physical activity, causing obesity and other health issues, started with the industrial revolution and steadily grew with the increase of screen time, initially attributed to TV; but, nowadays even more to smartphones and tablets. Last, in several ways, stress disorders attack modern, rich societies, and shows to have a slow but destructive character. Par excellence, all these problems could be signaled by monitoring technology, of course, preferably in an early stage.

Nowadays, just as many ICT-related problems regarding subjective well-being have been identified as there were problems with physical well-being. Consequently, recently, the original list has been extended with 5 additional ICT-related health problems:

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

The original 25-year-old list did have only six entries of which stress disorders was the only problem directly related to subjective well-being. Nowadays the list contains as many health problems on physical well-being as on subjective well-being.

With the steep progress in ICT, ICT has leaped from work to our homes. Consequently, the extended list concerns general health issues, not necessarily occupational health issues. However, the traditionally strict separation between private and work life is dissolving, as both blend more and more, at least for knowledge workers. Omnipresent internet and the many other ICT advancements have pushed flex work to become the new standard, providing workers in parallel freedom and constant work pressure.

Monitoring well-being's challenges at work

Will monitoring technology for well-being become worker's best friend? In solving this challenge, monitoring technology relies on clinical experience, while conducting experiments, interventions, and scalable approaches. And indeed, using monitoring technology it has been frequently claimed that all ICT-related occupational problems have been solved. For example, musculoskeletal problems can be prevented using persuasive technology, the problem of physical inactivity is approached

similarly, as are headache, diabetics, sleeping problems, and social isolation. So, it seems to be a case of ``one size fits all''. However, many solutions show to be fragile, random control trails are absent or conducted at a small scale, and solutions are at a gadget level, instead of at the level of aimed clinical solutions. The problem lies is the increasing tendency to just see what the computer shows. Perhaps this is why monitoring well-being at work has hardly become practice. The apps that force you to take a break share the aim for worker's well-being; but, they do not monitor anything.

Sense making

The speed and ease of computation, statistics, and even machine learning tempt investigators to torture the data until it confesses, simply 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 and never the need for replication has been so big, as ``*we cannot browse over the field of nature like cows at pasture*'' (Medawar, 1969). Regrettably, in search for new science and business opportunities, also many of the monitoring technology seems to be sparked from this practice[1].

If anything, monitoring technology requires making processes explicit, 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. As such, monitoring technology can also be a method to validate well-being theories, amongst many others. Moreover, when theoretical frameworks are properly defined, monitoring allows to test them in real world, far outside controlled lab environments. Then, we are confronted with life's incredible variance. Often, in human sciences, such variance is averaged out using advanced statistics. However, what to do if it has to work for each single individual? Then, even subtle differences can make the difference. When applied properly, ICT can provide solutions with its machine learning and pattern recognition branches.

Security

In principle, we can assume that monitoring technology's data can be stored for ever, if needed. When done so, would the cloud be an option or would the data be stored locally, in house, in a wearable, or in people's body? One or the other way, wireless transmission seems near-to unavoidable. Regrettably, par definition, this introduces a security risk.

Algorithms have been developed that deteriorate data over time, assuming that older data, long not accessed, and only weakly related to current data and processes is not of significant importance anymore. 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, we should try to understand, as events and processes seem to reoccur over time and over generations?

A combination of security measures could reduce the security risk significantly. For example, novel types of biometrics could be utilized for this purpose, in particular, when biosignals are already

[1] Well-executed sense making, with actuators applied (e.g., giving tactile feedback), requires to take into account worker's channel capacity, both for high level information (e.g., WWW search results) and low level signals (e.g., the sounds of a cash register). High level information need to map on worker's interests and background (van der Sluis, van den Broek, Glassey, R.J., van Dijk, E.M.A.G., & de Jong, F.M.G., 2014). Low-level signals need to take into account worker's signal processing capacity, including just noticeable differences between signals, memorability of sequences, and coping strategies (Goldstein & Brockmole, 2017). In all cases, preferably, a personally determined channel capacity is used.

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, this is very personal data when it concerns our well-being. Data that is not meant to be shared with everyone. This becomes particularly problematic when multiple monitoring technologies are combined, such as GPS, biosignals, and audio, as together they can unveil much more of 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 & Crampton, 1998) Meanwhile this can be extended by tracking all signals via ICT devices, such as smartphones, tablets, and laptops. Not only keystrokes; but, also complete texts can be captured. Audio surveillance is an obvious extension as well as 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 as a stressor. As this is a justified percept, when implementing monitoring technology for well-being, the worker should get full control over his personal data. Consequently, (s)he 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 is used for, what it is telling about them, and whether or not it can be distributed further?

The employer can try persuading his workers to provide more information. However, information needs to be placed in context (e.g., the worker’s personal circumstances), before a 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 need 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, in 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 he has a fever, stress, or 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 and is already used to reduce costs.

- In butcheries accidents still occur despite the use of professional knives. Workers simply forget having the knife in their hand when going to the bathroom or when they get in 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 sense their stress. Such a mouse can use pressure sensors and biosensors to determine the stress level. Via

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's safety. These sensors include cameras and microphones. These are used as caregiver's remote ears and eyes. This way a caregiver can monitor several elderly in parallel. General policy is that the elderly is in control of when their monitor technology is on and when it is off. However, this requires the elderly being able to make such decision.
- An example of invasive monitor technology that is used in daily practice to keep people working is an implantable cardioverter defibrillator (ICD). An ICD is a small device that's placed in the chest or abdomen that 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 enforcers (e.g., policemen) can wear camera's, including microphones. These record the policeman's handling when working. In case evaluation is needed, the camera recordings can be consulted by both the policeman and his employer, enabling both control and feedback on his functioning. Currently, this can only be 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 examples illustrates the use and broad application of embedded and wearable monitoring technology. Obviously, many more examples could have been provided. Most importantly is that the added value of the monitoring technology is clearly defined, including working conditions, access to data, and many other aspects, as have been discussed (Piwek, Ellis, Andrews, & Joinson, 2016).

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 behavior, which is required when aiming at a high(er) level of well-being. However, via a solution which 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 behavior, 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, very successful. The single one reason for this is that persuasive technology does not apply coercion. So, the worker is self-motivated to change his/her attitudes and behaviors. Especially, when changes have to be secured on the long run, strong intrinsic motivation is crucial. Alternatively, automated processed can be changed, possibly without worker's complete awareness, and, subsequently, fixed, replacing old processes.

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

- Lack of objective evaluation standards.
- Fragile integration of behavior 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.
- No representative target audiences in their design.

Taken together, persuasive technology has 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 for 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, it are five challenges that are among the most important. These challenges need to be vanquished for monitoring technology for well-being to become mature for occupational settings in general. However, for specific occupations, in specific contexts, the current state-of-the-art monitoring technology can already make a significant difference in worker's 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 view on issues such security and privacy will change. Moreover, undoubtedly, developments in embedded and wearable monitoring technology will rapidly speed-up and the technology will become accessible as it rapidly becomes cheaper. This leaves us with the two biggest and related challenges sense making and persuasive technology. The core challenge is the interpretation of that what is monitored and, subsequently, the choice of appropriate actions to be taken. This is a social sciences' (e.g., psychology and communication sciences) challenge instead of a technical challenge. It is on how well we understand our workers, their occupation, their working environment, and, actually, simply, their complete lives.

Conclusion

Our well-being and its monitoring 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 cannot only potentially increase our well-being, it can also help us understand it. So, 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 Electronic Performance Monitoring (EPM), which focused on an increase in the effectiveness and efficiency of production. EPM already showed its advantages and disadvantages, as did ICT at the workplace in general. Recently, the list of ICT's disadvantages has been doubled, which emphasizes technology's downside. Monitoring technology for well-being at work is facing its own challenges. On the one hand, some can be expected to be either vanish (i.e., privacy and security) or vanquished (i.e., issues with embedded and wearable technology). On the other hand, the challenges sense making and the inclusion of monitoring technology into persuasive technology can be expected to remain grand challenges for a considerable time. Nevertheless, as illustrated, for specific occupations, in specific contexts, monitoring technology can already increase worker's well-being.

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