Health Self-Management Applications in the Workplace

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Real-time, Actionable Feedback and Office Workers' Sitting Behaviour and Mental Fatigue

An Experimental Field Study

Abstract

Office workers are prone to developing work-related health problems because of their behaviour in the workplace. Two main causes for these health problems are prolonged sitting behaviour and mental fatigue. To improve worker sitting behaviour and mental fatigue, employers are increasingly adopting sensor technologies aimed at optimizing behaviour, but knowledge of the factors that drive effectiveness of these health self-management applications (HSMAs) is lacking. This paper empirically investigates the effects of real-time actionable feedback messages on employee health-related behaviour. The experimental field study contained a six-week intervention in which participants used a smart chair to monitor their sitting behaviour, and a keylogger while typing that registered their interkey interval as a proxy for mental fatigue. Participants were able to self-control the frequency at which the feedback was provided, and received feedback messages when standards for healthy behaviour regarding sitting or mental fatigue were exceeded. Findings show that receiving real-time actionable feedback messages on sitting behaviour does not impact the duration of the sitting event, whereas feedback messages on typing behaviour does influence participants in taking a break from typing. Over time in the experimental period, we observed a decrease in average sitting duration, but the average duration of a typing event did not change.

Introduction

Office workers are prone to developing several work-related health problems such as musculoskeletal problems (Mathiassen, 2006; Wilmot et al., 2012), cardiovascular disease (Wilmot et al., 2012), diabetes type 2 (Wilmot et al., 2012), obesity (Blair & Brodney, 1999; Puhl & Heuer, 2010), and mental sickness absence (Roelen et al., 2013). Two major causes of these work-related health problems are prolonged sitting behaviour and mental fatigue (Roelen et al., 2013; van Dijk, 2003; Wilmot et al., 2012). Employers have increasingly adopted workplace health promotion programs aiming at mitigating the adverse effects of prolonged sitting behaviour and mental fatigue. These programs include technical tools for employees that give them automated prompts for switching between seated and standing positions (Larouche et al., 2018) or for taking breaks from typing on a computer (de Korte, Huysmans, de Jong, van de Ven, & Ruijsendaal, 2012a).

To improve worker health and wellbeing in the workplace, giving feedback on current health-related work behaviour is an often-used strategy (Carter et al., 2011; Hermsen, Frost, Renes, & Kerkhof, 2016; Mattila et al., 2013). Feedback Intervention Theory states that the effectiveness of feedback in terms of improved behaviour and performance (Kluger & DeNisi, 1996)is influenced by the characteristics of the feedback provided. Earlier studies on feedback and worker behaviour show that feedback is more effective when it is actionable (Hysong et al., 2006) which means that customized advice is given on how to change the behaviour in question. Furthermore, feedback should be real-time, which means that the advice pertains to current behaviour, not past behaviour (Houde, Todd, Sudarshan, & Carrie Armel, 2013; Luke & Alavosius, 2011). Both the actionable and real-time aspect of feedback messages improves their effects on behaviour, which is evidenced by the effects of health self-management applications in the areas of patient (Lorig et al., 2001) and consumer behaviour (Macridis, Johnston, Johnson, & Vallance, 2018). Employers are seeing these benefits and are increasingly providing employees with smart devices that use real-time actionable feedback mechanism (Jacobs et al., 2019). However, it is unknown whether the real-time actionable feedback given by these smart devices actually leads to intended behavioural changes by employees (Mattila et al., 2013). Employees are different from consumers in that sense that they use health self-management tools in the workplace, where they are under pressure from deadlines and colleagues. This makes it more difficult to alter behaviour. Therefore, we aim to investigate the effects of real-time actionable feedback on employee health-related work sitting and typing behaviour

Specifically, our first research goal is to examine the effect of real-time, actionable feedback on prolonged sitting behaviour of office workers. Although the recommended maximum duration of consecutive sitting is 55 minutes (Ryan, Grant, Dall, & Granat, 2011), many office workers do not meet this recommendation (Netten, Van Der Doelen, & Goossens, 2013). One of the reasons for prolonged sitting is that people simply do not know that they are sitting too long (Shrestha et al., 2018). To increase this awareness, technical tools have been developed to provide real-time feedback on their sitting behaviour (Goossens, Netten, & Van der Doelen, 2012), that is, feedback given exactly when the behaviour should change, as opposed to retrospective feedback, where at the end of a period (e.g., half a day or a whole day) feedback over the whole period is given to determine which behaviours went well and which behaviours can be improved.

Some previous studies have examined the effectiveness of real-time feedback tools in reducing prolonged sitting behaviour, for example, in studies on smart chairs that send feedback signals when sitting for long periods or a bad posture are detected. In one study, employees received real-time feedback through chair vibrations and warning lights on a tab (Roossien et al., 2017). These feedback signals, however, had little to no effect on worker prolonged sitting behaviour, as the worker only received a tactile feedback signal indicating that something was wrong without clearly indicating what the harmful behaviour was and how it could be changed (Roossien et al., 2017).

The lack of actionability of the feedback made it difficult for workers to self-regulate their behaviour, because they first had to interpret the signal and compare it with the desired behaviour before they could figure out what to do. Receiving actionable feedback on how to change behaviour increases the effectiveness of feedback regarding prolonged sitting behaviour (Larouche et al., 2018), and therefore we aim to add actionable advice to the feedback signals given to workers to self-regulate their sitting behaviour.

Our second research goal is to examine whether real-time, actionable feedback on emerging mental fatigue that arises while typing on a computer can lead employees to take a break. Literature suggests that employees become less fatigued if they can regulate their work breaks autonomously (Trougakos, Hideg, Cheng, & Beal, 2014). Unlike pre-scheduled breaks, such as time-based breaks imposed by Repetitive Strain Injury (RSI)-prevention programs on a computer, real-time feedback enables workers to tailor their break-taking behaviour to their personal current state of mental fatigue.

Workers are often unable to notice their own mental fatigue at an early stage (Zhang, Gong, Miao, Zhu, & Yang, 2011), with the consequence that they keep working until there are signs of serious mental fatigue (such as delayed reactions and increased error rates). Providing workers with early-stage real-time feedback on mental fatigue, enabling self-regulation and containing actionable messages, requires validated tools that can measure emerging mental fatigue in an office environment without impeding the performance of work tasks. Recent research has yielded tools that measure keystroke intervals during typing and have used these intervals as a proxy of mental fatigue (de Jong, Jolij, Pimenta, & Lorist, 2018; Pimenta, Carneiro, Novais, & Neves, 2014). The value of these tools is above all that they can provide real-time feedback on mental fatigue at an early stage in the workplace. Real-time feedback can enable workers to change their typing behaviour to avoid the occurrence of severe mental fatigue. Therefore, our second goal is to examine whether real-time actionable feedback can prompt workers to take a break from typing early to recover from mental fatigue.

A third research goal of this study is to investigate the influence of the frequency with which workers receive real-time actionable feedback on their sitting behaviour and emerging mental fatigue. Literature shows that individuals who want to improve aspects of their behaviour request to receive more often feedback (Kluger & Adler, 1993), and that a higher frequency results in an accumulation of effects of feedback (Lurie & Swaminathan, 2009). Therefore, we aim to examine whether increased self-controlled feedback frequency has a moderating effect on the effectiveness of real-time actionable feedback on worker sitting behaviour and break-taking behaviour.

This research aims to make various contributions to the research literature on the role of feedback in self-management of health-related behaviour in the workplace. First, using insights from feedback intervention theory, we investigate the effectiveness of real-time actionable feedback delivered by a smart chair on employee self-regulation of sitting behaviour. Second, we investigate the effectiveness of real-time actionable feedback given to employees to take a break from typing to recover from early mental fatigue, thereby applying a recently developed technique that uses keystroke intervals to assess emerging mental fatigue.
Finally, our research provides practical implications for how real-time actionable feedback can be used in sensor and intervention technologies to enable workers to better regulate their health-related work behaviour.

Theoretical Background

Real-time actionable feedback

Feedback in general is a piece of evaluative information about previous behaviour (Anseel et al., 2009; Sargeant et al., 2009), often including an external or personal norm that is relevant for this behaviour. The effectiveness of feedback is affected by many factors related to the feedback itself, the ways it is provided, and the receiver of the feedback. Two main feedback-related factors we focus on in the present research are the timing of feedback, and the actionability of feedback. Regarding the timing of feedback, feedback intervention theory states that feedback is more effective in adapting behaviour if there is a shorter time between displayed behaviour and receiving feedback on that behaviour (Kluger & DeNisi, 1996). The reason for this is that real-time feedback can direct attention to immediate causes, motives and conditions of the current behaviour, allowing direct targeted adjustments to be made. Recent studies support this claim of increased effectiveness of real-time feedback (Houde et al., 2013; Luke & Alavosius, 2011). Effects of real-time feedback have been predominantly found in experimental studies (Kulik & Kulik, 1988; Webb, Stock, & McCarthy, 1994), and in a few field studies where organizational behaviour such as quality control (Mason & Redmon, 1993)and training of teaching skills was targeted (Reid & Parsons, 1996). Most research in the work environment, however, examines feedback on behaviour that is given in a retrospective manner, for instance, by giving feedback on a complex task only after it has been fully completed (Alder, 2007). As contemporary smart devices with built-in sensor technology are capable and intended to provide immediate feedback on behaviour, we need additional research to examine the effectiveness of real-time feedback provided by those devices. We aim to close this research gap by investigating whether real-time feedback can help workers in self-regulating health-regulated behaviour in the workplace. Furthermore, as soon as feedback is given real-time, the worker should be enabled to easily change the behaviour when necessary, so the feedback should be actionable. Actionable feedback is feedback that is timely, individualized, non-punitive, and customizable (Hysong et al., 2006). The timely and customizable characteristics give workers clear information and directions on how to act in order to improve behaviour (Larouche et al., 2018). The non-punitive nature prevents workers from experiencing negative emotions in response to the feedback, thereby giving room for learning and self-improvement (Cannon & Witherspoon, 2005). Current real-time feedback systems in the workplace often do not include actionable feedback, and only show how a worker negatively deviates from standards or norms (Roossien et al., 2017) without giving advice on how to effectively adjust that behaviour. Research suggests that feedback providing actionable information is highly effective in changing behaviour even when it is not given real-time (Larouche et al., 2018). Therefore, in this study, we combine the real-time feedback with actionable information to optimize the feedback effects on worker behaviour.

Sitting behaviour

Prolonged sitting is very common behaviour for office workers. In literature, recommendations on the maximum duration of sitting bouts vary from 20 to 55 minutes (Goossens et al., 2012; Netten et al., 2013). These recommended norms, however, are often exceeded (Evans et al., 2012) as office workers sit on average 5.4 hours per working day behind a desk (Roossien et al., 2017) and 7.1 hours per working day in total, i.e. including sitting during lunch and meetings. More than 21% of working days is spent in sitting events longer than 55 minutes (Netten et al., 2013). This prolonged sitting causes a wide range of illnesses, including musculoskeletal problems (Mathiassen, 2006; Wilmot et al., 2012), cardiovascular disease (Wilmot et al., 2012) and diabetes type 2(Wilmot et al., 2012).

These diseases can be prevented by using interventions that alter the sitting behaviour of office workers. Interventions examined in previous research include advice or counselling on physical activity (Marshall, Leslie, Bauman, Marcus, & Owen, 2003; Opdenacker & Boen, 2008; Østerås & Hammer, 2006), fitness testing (Aittasalo, Miilunpalo, & Suni, 2004), and e-mail messaging about healthy eating and active living (Plotnikoff, McCargar, Wilson, & Loucaides, 2005). These interventions showed no significant alteration of sitting behaviour. A review of workplace health promotion interventions from Malik et al. (2014) recommends including the use of sensor technology to objectively monitor sitting behaviour based on which specific feedback on actual durations of sitting bouts can be given instead of using general information and behavioural guidelines as input for the feedback. The application of these technologies indeed caught on, and especially activity monitors that monitor daily exercise in various ways were used on a large scale to monitor sitting behaviour and physical activity (Donath, Faude, Schefer, Roth, & Zahner, 2015; Evans et al., 2012; Neuhaus et al., 2012). These interventions, however, only used retrospective feedback, instead of also generating real-time actionable feedback messages.

A few recent studies used smart chairs to examine real-time feedback on sitting behaviour (Goossens et al., 2012; Roossien et al., 2017), sometimes combined with activity monitors. These interventions, however, sorted little to no effect. Possible explanations included a lack of actionable information (Goossens et al., 2012; Roossien et al., 2017), because workers received a tactile feedback message (the chair buzzed), but had to press a button on a label attached to the chair to get more information about what was wrong. If they pressed the button, they were still only shown an orange light indicating where on the chair the abnormal sitting behaviour occurred, but no advice was given on what to do (i.e. change leg position, stand up, sit up straight). Due to this lack of actionable feedback, the real-time feedback may not have been effective.

Real-time feedback is given when current behaviour is deviating from the norm for that behaviour. In case of sitting behaviour in the present study, real-time feedback gives information on the duration of a current sitting event. Such real-time feedback that is specified to the actual current sitting behaviour of the individual is suggested to be more effective in changing that behaviour than more general feedback (Huang et al., 2019). Furthermore, feedback is more likely to be effective when it is actionable (Bond et al., 2014; He & Agu, 2014). For example, actionable feedback messages concerning sitting behaviour are “Stand up” and “Walk for 2 minutes” (Larouche et al., 2018). We therefore propose that real-time, actionable feedback on prolonged sitting behaviour may enable office workers to reduce the duration of sitting events.

More specifically, we expect that the effects of real-time actionable feedback on sitting behaviour of office workers are twofold. First, real-time actionable feedback on a prolonged sitting event is likely to prompt workers to stand up from their chair within a relatively short time frame (e.g., 15 minutes) (Lechermeier & Fassnacht, 2018). Distinct yet related to this direct feedback effect on standing up behaviour, the feedback may make workers more aware of their prolonged sitting behaviour and motivate them to shorten the duration of the sitting event. To capture both feedback effects, we accordingly hypothesize:

1A. Real-time actionable feedback (versus no feedback) on prolonged sitting prompts office workers to stand up from their chair earlier.

1B: Real-time actionable feedback (versus no feedback) on prolonged sitting decreases the duration of sitting events of office workers.

We investigated the effects of real-time, actionable feedback on sitting behaviour in a field experiment of 6 weeks (see method). We therefore also tested whether feedback on sitting behaviour produces a learning effect over time. It is plausible that, over time, participants will not only become more and more aware of their prolonged sitting behaviour through repetitive feedback, but also learn to limit long sitting bouts. Therefore, we hypothesize:

1C: Time has a negative effect on duration of sitting events, such that as time progresses during the experiment, the duration of the sitting events decreases.

Mental fatigue

Mental fatigue is a state of tiredness which is tied to multiple work-related problems, such as loss of efficiency (Boksem & Tops, 2008), distraction (Boksem, Meijman, & Lorist, 2005), and difficulties in planning and adapting activities (Van der Linden & Eling, 2006; Van der Linden, Frese, & Sonnentag, 2003). Mental fatigue may also impact health, leading to prolonged fatigue, deteriorated sleep quality, psychosomatic complaints, and emotional exhaustion (Sluiter, De Croon, Meijman, & Frings-Dresen, 2003)

Mental fatigue is a reason for changing fatigue-related behaviour. Fatigue makes that the effort to concentrate on work no longer pays off, because the work slows down or the results are of lower quality (Boksem & Tops, 2008). Previous studies on mental fatigue reduction have shown that taking small breaks during the day allows workers to recover from mental fatigue and stay fit during working days (Kim, Park, & Niu, 2017) However, research suggests that interventions to stimulate breaks at predetermined times show no effect (Trougakos et al., 2014), because workers prefer to autonomously self-regulate breaks from work, so without a timer or manager telling at what time exactly a break should be taken. Self-regulation of break-taking behaviour is complicated, however, because workers tend not to notice when they get fatigued until they are extremely fatigued (Zhang et al., 2011). When they notice that they are extremely fatigued, their need for recovery time is very high, whereas this extended time is not always available, causing a lack of recovery during the working day (Trougakos & Hideg, 2009). Lack of recovery from mental fatigue is associated with productivity loss (Ricci, Chee, Lorandeau, & Berger, 2007) and loss of general health (Sluiter et al., 2003). Therefore, real-time feedback on emerging mental fatigue could help workers take a timely break, thereby minimizing the development and consequences of severe mental fatigue.

Real-time feedback on mental fatigue in the office environment, however, is hard to give, because there is a lack of methods for measuring emerging mental fatigue that are useable in office work. Known methods are either retrospective, so not real-time, or very invasive, making it impossible to use them on a regular basis in the work environment.[1] Recent developments using keystroke intervals in typing behaviour as a proxy for mental fatigue have opened up the possibility to measure emerging mental fatigue of office workers in a real-time, non-invasive way (de Jong et al., 2018; Pimenta et al., 2014). This measurement method allows users to receive real-time feedback that enables them to self-regulate their fatigue-related behaviour. In this approach, the interval between keystrokes is used to determine the mental fatigue of office workers. Using this method, real-time actionable feedback can be given, allowing workers to consider this feedback information when deciding to take a break. Thus, such real-time feedback allows autonomous self-regulation of break-taking behaviour, which is likely to help reduce mental fatigue (Trougakos et al., 2014).

We expect that the effects of real-time actionable feedback on mental fatigue of office workers are threefold. First, real-time actionable feedback on mental fatigue is likely to prompt workers to take a break within a relatively short time frame (e.g., 15 minutes) (Lechermeier & Fassnacht, 2018). Besides this direct feedback effect on break-taking behaviour, the feedback may make workers more aware of their emerging fatigue and motivate them to shorten the duration of typing events. In addition, we expect that mental fatigue feedback will produce a learning effect over time in the six-week experiment we conducted. Over time, participants are likely to take a break more quickly in response to the feedback they receive, thereby reducing the duration of typing events.

To capture these three feedback effects, we accordingly hypothesize:

[1] Known methods for measuring mental fatigue are a psychomotor vigilance task (PVT) at the end of the day (Riethmeister, Bültmann, Gordijn, Brouwer, & de Boer, 2018), questionnaires (Sluiter et al., 2005, 2003), or an Electroencephalogram (EEG) (Liu et al., 2018; Wascher, Heppner, & Hoffmann, 2014), requiring the subjects to use an EEG device mounted on their head for the time of the study.

2A: Real-time actionable feedback (versus no feedback) on mental fatigue prompt workers to take a break from typing earlier.

2B: Real-time actionable feedback (versus no feedback) on mental fatigue decreases the duration of typing events of office workers.

2C: Time has a negative effect on duration of typing events, such that as time progresses during the experiment, the duration of typing events decreases.

The moderating effect of Feedback frequency

Feedback frequency, defined as the number of times a feedback intervention was provided (Kluger & DeNisi, 1996), is known as one of the drivers of feedback effectiveness. Higher feedback frequency improves the learning of new behaviour (Salmoni, Schmidt, & Walter, 1984). This learning effect of feedback frequency is further strengthened when feedback receivers can self-control feedback frequency (Chiviacowsky & Wulf, 2002). Individuals who are able to utilize the feedback for improving their behaviour, get motivated to ask for more feedback, which further increases their behavioural adjustments and thus the effect of the feedback (Chiviacowsky & Wulf, 2002).

Earlier studies on feedback frequency in the work environment show an inverted U-shaped effect for externally imposed feedback frequency, so the increase of frequency improves the outcomes, up to a tipping point, after which the outcomes worsen with every increase of feedback frequency (Lam et al., 2011). This happens because too frequent feedback overwhelms the cognitive capacity of the receivers, thereby invalidating them to improve their behaviour (Lam et al., 2011). For self-controlled frequencies, however, the effect of frequency has been found to be linear (Wulf, 2007), because participants will only ask for more feedback if they feel able to process the feedback (Wulf, 2007), so they will not become overwhelmed. However, this frequency effect has not yet been examined for real-time actionable feedback on health-related work behaviours in the work environment (Hermsen et al., 2016). Therefore, we aim to give more insight in this lacuna by examining how self-controlled feedback frequency may moderate the effects of real-time actionable feedback on health-related work behaviour among office workers

Accordingly, it is expected that higher feedback frequency strengthens the effects of real-time actionable feedback on office workers' sitting behaviour and break-taking behaviour.

This moderating effect is hypothesized for all 6 sub-hypotheses regarding the effect of real-time actionable feedback messages on sitting behaviour and break-taking behaviour of office workers. The moderated hypotheses for 1A and 2A are called 3A and 4A. The moderated hypotheses for 1B and 2B are called 3B and 4B. The moderated hypotheses for 1C and 2C are called 3C and 4C.

Methods

Experimental field study and procedure

To test the study hypotheses, we have conducted a 6-week experimental field study among university staff. In this field study, the participants received multiple sensor tools that obtained real-time data on their sitting behaviour and mental fatigue developed during typewriting, and sent it to a data platform. Dependent on the experimental condition regarding feedback frequency (see description of manipulation below), participants may or may not receive a feedback message by SMS when their sitting or typing behaviour exceeded predetermined standards.

Setting

The organization in which the experimental field study took place is a medium-sized division of a large university in the Netherlands. The health and safety officer of this division had a strong focus on preventing illnesses among employees and gave permission for the field study to be conducted. The experimental protocol for the study was approved by the designated research ethics committee of the cooperating university.

Participants

Participants were recruited by the health and safety coordinator of the institution. Participants were eligible to participate if they had an employment contract of at least 0.8 FTE (31,4 hours per week) and were not suffering from long-term illnesses or having adjusted tasks as part of a re-integration trajectory at the time of the experiment. A total of 22 office workers started the experiment (see Figure 1), of which two dropped out due to health issues and family circumstances. Twenty participants completed participation, of which two had data absence and were excluded from analyses. The remaining 18 participants (six were female) had an average age of 43 (SD_{age} =11,1) and an average employment duration of 14 years ($SD_{employment}$ = 9). Most participants (83%) had a university degree, while 17% had a vocational degree. Analyses of sitting behaviour included data of 16 participants, and the analyses of mental fatigue included data of 12 participants (see Figure 1 for a participant flow chart). The spread of employees across the job spectrum was satisfactory, including both junior and senior educational and scientific staff, as well as support staff.

Sensor tools and feedback

Measuring of sitting events

Employees were using an Axia Smart Chair (BMA/SBSeating, Zwolle, the Netherlands) that registered their sitting behaviour. If participants were sitting for 55 minutes in a row, and had not yet received the maximum number of feedback messages (see below description of manipulation of feedback frequency), a feedback message was sent containing the observation that they had been sitting for a long period of time and the advice to stand up and take a short stroll.

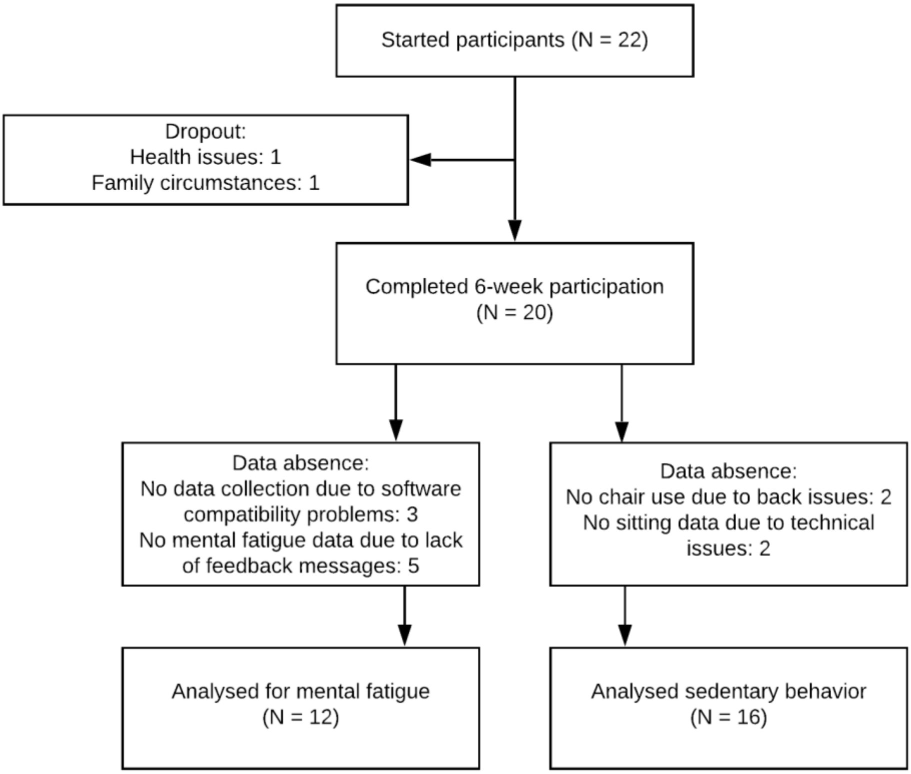

Figure 1: Participant flow chart

Measuring of mental fatigue in typewriting

Participants used a keylogger in a QWERTY keyboard to monitor their interkey intervals (aXtion, Groningen, the Netherlands) based on which their level of mental fatigue was measured (de Jong, Bonvanie, Jolij, & Lorist, 2020). The interkey interval was calculated using a moving average of all keystrokes over a 15-minute window and registered in the research database every minute. The average interkey interval between 9AM and 10AM was used as benchmark, under the assumption that during this hour, participants would not yet be fatigued. If there was no activity between 9AM and 10AM, the last known benchmark was used. When participants' interkey interval during the working day became 10% or more slower than the benchmark, and participants had not yet received their maximum number of feedback messages (see below description of manipulation of feedback frequency), they received a feedback message saying that their typing behaviour shows that they seem to get fatigued, and therefore they are advised to take a break.

Independent variables

Feedback frequency: the participants were assigned to one of the three feedback frequency conditions (low, medium or high feedback frequency) randomly. However, right from the start of the experiment, participants were able to self-control feedback frequency by altering the frequency at which they received feedback through a web-interface. That is, feedback frequency could be set to low (minimum 1 and maximum 3 text messages per day), medium (4-7 messages) or high (8-12 messages) levels. Of the 20 participants who completed participation, 12 decided to change the frequency with which they received feedback, six of which changed more than once. During the experiment, all frequencies were used for different periods by multiple participants. At the end of the 6-week experimental period, 1 participant received feedback on high frequency, 9 received medium frequency feedback, and 10 received low frequency feedback.

To ensure that participants who did not exceed the predetermined standards for sitting behaviour and mental fatigue received at least the minimum number of feedback messages of their chosen frequency, default messages were sent. Default messages said "No deviations from the norms have been registered in the last time period. Keep paying attention to your work behaviour". Depending on the chosen frequency, a check was performed 1 to 8 times a day to see whether in the period before the check a feedback message was sent. If not, the default message was sent. The times at which the default message check was executed are shown in Figure 2. As soon as the maximum number of messages was reached, both feedback messages and default messages were stopped. On average, participants received 2,13 default messages per experiment day.

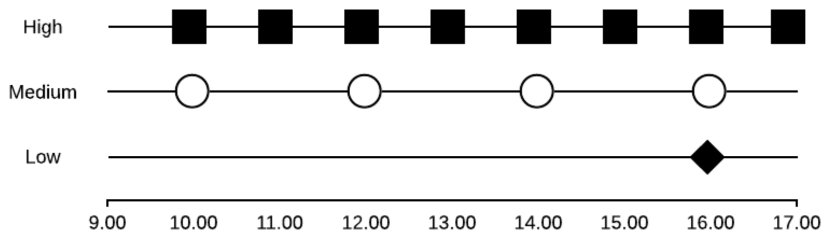

Figure 2: Times at which a check was performed to see whether a default message must be sent

All participants received an e-mail once a day with an overview of their sitting behaviour and mental fatigue during the day.

Feedback message (yes or no): indicates whether or not the participant received a real-time, actionable feedback message in response to a prolonged sitting event with a duration longer than 55 minutes or in response to emerging mental fatigue developed during typing.

TimeStamp: numeric variable that contains the experiment day (1-46) and representation of the hour at the end of the sitting or typing event. This variable was created to test hypothesis 1C and 2C predicting a learning effect of feedback on sitting behaviour and break-taking behaviour over time.

Measures

Two separate datasets were used, one with the data regarding sitting events and one with data regarding typing events. These data were nested within participants, with sitting and typing events being the unit of analysis. A sitting event started when the participant sat down for at least 55 minutes on the smart chair and ended when the participant stood up. A typing event started when the measurement of interkey intervals indicated that a participant became tired and stopped when the participant took a break of at least 15 minutes.

Dependent variables

Standing up (yes or no): indicates whether or not participants stood up from their chair within 15 minutes after exceeding the norm of sitting longer than 55 minutes continuously.

Taking a break (yes or no): indicates whether or not participants took a break within 15 minutes after their keystroke interval became 10%, or more, slower than their benchmark, which was used as a proxy for mental fatigue.

Duration of sitting event: the duration in minutes of a sitting event exceeding the 55 minutes norm.

Duration of typing event: the duration in minutes of a typing event in which mental fatigue emerged.

Statistical analyses

All measures are reported for sitting and typing events that exceed pre-set norms of sitting longer than 55 minutes (sitting event) or 10% slower keystroke interval in typewriting (typing event); these sitting and typing events are denoted by variable **e**. Sitting and typing events are produced by individual subjects **s** (**s**=1..18) and at a certain point in time as denoted by timestamp. Timestamp is defined by the experimental day (1-46) on which events occurred before the decimal point and the elapsed time of the day in percentages when events occurred after the decimal point (**timestamp**=1,00..46,99). For each sitting or typing event, there is a function **s(e)** that refers to the subject of the event, and a function **timestamp(e)** indicating the timestamp at which the event occurred. During a sitting or typing event either a feedback message is generated to advice the subject to stand up from the chair or take a break from typing, or not. This is represented by Boolean function **feedback(e)**.

Feedback effects on standing up and taking a break

To test hypothesis 1A and 2A, we examined whether feedback(e) (yes or no) has an effect on subjects' direct action, that is whether or not they stand up (standingup(e)) from the chair (H1A) or take a break (break(e)) from typing (H2A) within 15 minutes. Thus, **standingup(e)** and **break(e)** are a Boolean function with value true if **dur(e)** <15, otherwise it is false. Given that **standingup(e)** and **break(e)** are a binary variable, we conducted logistic regression analysis using xtlogit in Stata (StataCorp, 2019). Given the nested data structure, the xtset command was used to take into account that standing up and taking a break were nested within subjects. The logistic regression equation is

$$log\left(\frac{p}{1}-p\right) = M + a * feedback(e) + \Sigma(bs * s(e)) + \varepsilon$$

where log (p/1-p) is the odd ratio for standing up (H1A) or taking a break (H2A), M is the mean of the binomial distribution of standing up or taking a break, $a * feedback(e)$ is the independent variable feedback(e) and its coefficient a (fixed effect at sitting or typing event level), $\Sigma(bs * s(e))$ is the random variance at the subject level, and ε is the random error at the sitting or typing event level.

To test hypothesis 3A and 4A, we examined whether feedback frequency moderated the effects of feedback(e) on standing up (H3A) or taking a break (H4A). We conducted a logistic regression analysis for the binary dependent variable of standing up or taking a break with the following equation:

$$\mathrm{log}\left(\frac{\mathrm{p}}{1}-\mathrm{p}\right) = \mathrm{M} + \mathrm{a1} * \mathrm{feedback(e)} + \mathrm{a2} * \mathrm{freq} + \mathrm{a3} * \mathrm{feedback(e)} * \mathrm{freq} + \Sigma\big(\mathrm{bs} * \mathrm{s(e)}\big) + \varepsilon$$

where $log\ (p/1-p)$ is the odd ratio for standing up (H3A) or taking a break (H4A), M is the mean of the binomial distribution of standing up or taking a break, $a1 * feedback(e)$ is the independent variable feedback(e) and its coefficient a_1, $a2 * freq$ is the independent variable feedback frequency(e) and its coefficient a2, $a3 * feedback(e) * freq$ is the interaction between feedback(e) and feedback frequency(e) and its coefficient a3, $\Sigma(bs * s(e))$ is the random variance at the subject level, and ε is the random error at the sitting or typing event level.

Effects on duration of sitting and typing events

To test hypothesis 1B and 2B, we examined the effect of feedback(e) on the total duration of sitting events (H1B) or typing events (H2B), notated as **dur(e**). A multilevel regression analysis was conducted using the xtreg command in Stata. The xtset command was used to account for the nested structure of the data (sitting or typing events occur within individual subjects). The regression equation is

$$dur(e) = D + a * feedback(e) + \Sigma(ds * s(e)) + \varepsilon$$

where $dur(e)$ is the dependent variable duration of the sitting (H1B) or typing (H2B) event, D is the overall mean of the duration of sitting or typing events (i.e. $dur(e)$), $a * feedback(e)$ is the independent variable feedback(e) and its coefficient a, $\Sigma(ds * s(e))$ is the random variance for the subject, and ε is the random error at the sitting or typing event level.

To test hypothesis 3B and 4B, we used a multilevel regression analysis for the dependent variable dur(e) with the equation

$$dur(e) = D + a1 * feedback(e) + a2 * freq + a3 * feedback(e) * freq + \Sigma(bp * s(e)) + \varepsilon$$

where $dur(e)$ is the dependent variable duration of the sitting (H3B) or typing (H4B) event and D is the overall mean of the duration of sitting or typing events (i.e. $dur(e)$), while the remaining terms are equal to those in the previous equation for testing H2a and H2B

Effects over the 6-week experimental period

In the last analyses, we have tested whether time (i.e. timestamp) influences the duration of sitting or typing events (i.e. dur(e)). We also explored whether feedback frequency (i.e. freq) moderated such time effects. Specifically, we conducted two multilevel regression analyses for testing the effect of time. The first analysis tests hypotheses 1C for the duration of sitting events and 2C for the duration of typing events, and does not include feedback frequency and is using the following equation:

$$dur(e) = D + a1 * timestamp(e) + \varepsilon$$

The second analysis tests whether feedback frequency moderates the time effects on the duration of sitting events (H3C) and the duration of typing events (H4C) using the equation

$$dur(e) = D + a1 * timestamp(e) + a2 * freq(e) + a3 * timestamp(e) * freq(e) + \Sigma(d's * s(e)) + \varepsilon$$

Results

Data overview

Table 1 shows an overview of relevant descriptive statistics for the study variables for both the sitting and typing events. Only the sitting and typing events for which the pre-set norm was exceeded are included in the data set.

Due to errors in the feedback settings, several participants received a message about their prolonged sitting (> 55 minutes) too late. Unfortunately, these events with delayed feedback could not be included in the analyses of standing up and duration of sitting events. This explains the low number of 19 sitting events where a real-time, actionable feedback was sent. As a result, the three feedback frequency conditions contained too few events and the available events were not evenly distributed across the conditions to test whether feedback frequency would moderate the effects of real-time actionable feedback. Therefore, we were unable to test hypotheses 3A and 3B. These limitations are further addressed in the Discussion section.

	Sitting events	Typing events
Number of events	245	1065
Number of subjects	16	12
Average number of events per subject (min – max)	15,3 (1 – 34)	88,7 (6 – 128)
Number of events where a relevant feedback message was sent	19	93
Average number of events with feedback, per subject	1,2	7,8
Average duration of event (minutes)	65,74	53,71
Average duration of event where a relevant text was sent (minutes)	39,05	43,11

Table 1: Data overview

Hypothesis testing

Feedback effects on standing up and taking a break

An overview of the results is given in table 2.

Standing up from the chair

To test hypothesis 1A, we examined whether receiving a feedback message after sitting for 55 minutes, compared to not receiving feedback, resulted in more immediate standing-up behaviour (Standing up). We found no significant effect of feedback on standing up (coef = -0,499, p = 0,460, see table 2, H1A), indicating that real-time actionable feedback did not lead to immediate standing-up behaviour. Thus, hypothesis 1A was not supported.

Taking a break from typing

To test hypothesis 2A, we examined whether receiving a feedback message, compared to not receiving feedback, after exceeding the norm of 10% slower interkey interval, resulted in more direct break-taking behaviour (Break). We found a significant effect (coef = 0,580, p = 0,036), indicating that a real-time actionable feedback message indeed leads to taking a break from typing within 15 minutes more often (see table 2, H2A). Hypothesis 4A predicting that feedback frequency would moderate the effect of feedback on direct break-taking behaviour could not be confirmed (coef = -0,197, p = 0.287, see table 2, H4A).

	(H1A) Standing up	(H2A) Break	(H4A) Break
Feedback	-0.499	0.580**	-0.352
	(0.676)	(0.276)	(0.682)
frequency			-0.197
			(0.185)
feedback*frequency			0.618
			(0.405)
_cons	-1.395***	-1.417***	-1.127***
	(0.228)	(0.106)	(0.290)
N	245	732	732
Pseudo R^2	.z	.z	.z
Standard errors are in parenthesis			
*** p<0.01, ** p<0.05			

Table 2: Regression results for standing up and taking a break

Effects on duration of sitting and typing events

An overview of the results is given in table 3.

Duration of sitting events

To test hypothesis 1B, we examined whether receiving a feedback message, compared to not receiving feedback lowered the duration of sitting events (dur(e) sitting). We found no significant effect of feedback(e) on duration of sitting events (coef = -10,92, p = 0,483, see table 3, H1B), indicating that feedback messages do not lead to shorter sitting events. Therefore, we cannot confirm hypothesis 1B predicting that actionable feedback decreases the duration of sitting events.

Duration of typing events

To test hypothesis 2B we examined whether receiving a feedback message, compared to no feedback message, lowered the duration of typing events. We found that the duration is significantly affected by receiving a feedback message (coef = -11.773, p = 0.032, one-tailed), thereby supporting our hypothesis 2B (see table 3, H2B). We found no support for Hypothesis 4B predicting that feedback frequency would moderate the effect of feedback on the duration of typing events (coef 3.192, p = 0.353, see table 3, H4B)

	(H1B) Dur(e) sitting	(2HB) Dur(e) typing	(H4B) Dur(e) typing
Feedback	-10.916	-11.773**a	-9.829
	(15.545)	(6.376)	(15.522)
Frequency			3.192
			(3.436)
feedback*frequency			-1.322
			(9.484)
_cons	128.547***	54.883***	50.146***
	(9.271)	(2.013)	(5.484)
N	245	732	732
Pseudo R^2	.z	.z	.z
Standard errors are in parenthesis			
*** p<0.01, ** p<0.05, * p<0.1, [a] one-tailed test			

Table 3: Regression results for event-level behaviour (duration of sitting and typing events)

Time effects over the 6-week experimental period

An overview of the results regarding the effects of time on the duration of sitting events and typing events over the course of the 6-week experimental period is given in table 4.

Duration of sitting events

We examined whether time (i.e. timestamp) lowered the duration of sitting events during the experimental period of 6 weeks (hypothesis 1C). This time effect was significant (coef = -0,711, p = 0,010, see table 4, H1C), indicating that as time progressed during the experiment, the duration of the sitting events decreased. We then explored whether this time effect was moderated by feedback frequency (freq). Feedback frequency had no significant moderation effect in the relationship between timestamp and duration of sitting events (see table 4, H3C).

Duration of typing events

Lastly, we examined whether receiving feedback on mental fatigue developed during typing behaviour lowered the duration of a typing event over the 6-week experimental period. This time effect was not significant (coef = 0.069, p = 0.614, see table 4, H2C), so hypothesis 2C was not supported. Hypothesis 4C, stating that the frequency of feedback strengthens the decrease of duration as time progressed during the experiment, was also not supported (coef =5.709, p = 0.322, see table 4, H4C).

	(H1C) dur(e) sitting	(H3C) dur(e) sitting	(H2C) dur(e) typing	(H4C) dur(e) typing
Timestamp	-0.711***	0.358	0.069	-0.556
	(0.277)	(0.931)	(0.137)	(0.369)
Frequency		20.409		-5.709
		(19.723)		(5.765)
Timestamp*frequency		-0.969		0.428*
		(0.807)		(0.228)
_cons	148.803***	127.093***	51.953***	60.611***
	(14.122)	(26.273)	(3.969)	(9.907)
N	245	245	732	732
Pseudo R^2	.z	.z	.z	.z
Standard errors are in parenthesis				
*** p<0.01, ** p<0.05, * p<0.1				

Table 4: Regression results over the 6-week experimental period (duration of sitting and typing events)

Assumption testing

Regarding mental fatigue, the underlying assumption was that taking a break timely would enable workers to recover from their mental fatigue. To test this assumption, we have examined whether the average interkey interval after a 15 – 45-minute break was lower than the interkey interval at the moment the worker started the break. We found no significant difference between the interkey interval just before and immediately after breaks. Therefore, we cannot confirm the assumption that breaks decreasing the mental fatigue of office workers. We come back to this finding in the Discussion section.

Discussion

Recap of the results

Table 5 presents an overview of all hypotheses that are tested, including their number and outcome. The presented results show that receiving real-time actionable feedback messages influences employees in taking breaks from typing, whereas no significant effects were found for sitting behaviour. That is, real-time actionable feedback on mental fatigue developed during typing prompted employees to take a break within 15 minutes and to reduce the duration of typing events. In addition, we also found a learning effect for sitting behaviour. Over time in the experimental period, we see that participants significantly shorten the duration of the sitting events, confirming the expected learning effects.

The results did not support the hypotheses stating that the relation between real-time actionable feedback and sitting and typing behaviour of office workers would be strengthened by a higher feedback frequency. Also, the assumption that a break decreases the mental fatigue of office workers cannot be confirmed using our data.

	Nr.	Main effect	Nr.	Moderating effect of feedback frequency
Direct effect				
Sitting	1A	Not supported	3A	Unable to test
Typing	2A	Supported	4A	Not supported
Event-level effect				
Sitting	1B	Not supported	3B	Unable to test
Typing	2B	Supported	4B	Not supported
6-week experimental period				
Sitting	1C	Supported	3C	Not supported
Typing	2C	Not supported	4C	Not supported

Table 5: Overview of the outcomes of all analyses

Implications for theory

The outcomes of this study show that real-time actionable feedback messages can help employees self-regulate their health-related work behaviour. This confirms two major principles from Feedback Intervention Theory suggesting that feedback is more effective when it is real-time and actionable. However, the feedback effects are different for sitting and typing behaviour, which we will look further into.

There are two main lines of thought that could explain the different outcomes for sitting and typing behaviour. First, there is a relevant difference between novelty and expectedness of information provided in feedback messages about sitting and typing events. The feedback on sitting events contains information that the employees are usually aware of: the norm of prolonged sedentary behaviour (i.e. sitting for more than 55 minutes) was known to the participants in this study, and they could monitor the duration of their sitting bouts themselves. The feedback on mental fatigue developed during typing, however, is different from that: as Zhang (2011) shows, people are unaware of their mental fatigue in an early stage. Therefore, the feedback information about their emerging mental fatigue was likely to be unexpected information to the participants. In the light of this difference in novelty and unexpectedness of feedback information, the different outcomes for sitting and typing events seem to confirm the idea of West (2000) that new, unexpected information induces a reflection process that can facilitate behavioural adjustment.

The second possible explanation for the different feedback effects for sitting and typing events, is the difference between the effect horizon of sitting behaviour and emerging mental fatigue while typing. In case of prolonged sitting behaviour, a feedback message was sent indicating that the norm regarding healthy sitting behaviour had been exceeded and including the advice to stand up from the chair. Such prolonged sitting events, however, do not affect health and performance in the immediate short run, but is most relevant for long-term health, i.e. the prevention of musculoskeletal or cardiovascular problems. The feedback on mental fatigue developed during typing, however, makes short-term effects salient: it explicitly indicated that the participants' current typing performance was decreasing due to fatigue. Therefore, acting upon a feedback on typing events did not only affect long-term health outcomes of mental fatigue, but also immediate performance of the worker. Therefore, the incentive is a lot more tangible, which could explain why people did tend to take a break from typing immediately in response to a feedback message, whereas feedback had no effect on their sitting behaviour.

The present results did not confirm our assumption that taking breaks from typing would reduce mental fatigue of workers. This non-effect contradicts findings of Kim, Park, and Niu (2017) demonstrating that breaks reduce the mental fatigue of office workers. There are two issues that may have caused the differences in outcomes between our research and that by Kim et al. (2017).

Firstly, we have used in our study breaks varying from 15-45 minutes, whereas Kim et al. (2017) focused on examining the effects of micro breaks (i.e. breaks to have a drink, to chat with a colleague, or to stretch or gaze out the window). The breaks that Kim et al describe are all breaks that focus on relaxation to recover from mental fatigue, whereas the breaks in the present research are periods where participants may have stopped typing but have not necessarily switched to relaxation activities. A participant can, for instance, read a paper, have a meeting, or have a discussion with a colleague in this time. Such activities might not be suitable for reducing mental fatigue. In this regard, Trougakos et al. (2014)showed that contact with colleagues can actually make mental fatigue even worse. Therefore, more research is needed into the actual activities during work breaks to examine how real-time actionable feedback on mental fatigue can help employees to recover from early-stage mental fatigue.

Secondly, our assessment of mental fatigue was based on objective measures of participants' interkey interval when typing, and the preand post-break measurements of those interkey intervals were compared to test the effect of breaks on mental fatigue reduction. Kim et al. used questionnaires to measure end-of-work negative affective states of workers, of which fatigue was one. These measures are subjective and generally assessed at the end of a working day, making it problematic to compare their microbreak effects with the 15-45-minute breaks used in the present study. Therefore, we would recommend to conduct further research on how different types of breaks assessed with different methods influence recovery from mental fatigue.

Practical implications

Our study shows that the use of real-time actionable feedback messages impacts health-related behaviours of office workers. A practical implication of our results is that workers who are probably unaware of their emerging mental fatigue developed during typing on a computer can immediately benefit from feedback messages saying that they get fatigued and recommending taking a break from typing. Furthermore, our results suggest that workers receiving feedback on their prolonged sitting behaviour do not change their behaviour immediately, but they do learn over time and reduce the duration of their sitting events. As such, these short-term feedback effects on break-taking behaviour and long-term feedback effects on sitting behaviour are promising and beneficial for worker health. Remaining questions are how to stimulate workers to alter prolonged sitting behaviour in the short run, and what kind of breaks are best to take in order to decrease mental fatigue.

Employers, however, should be careful in implementing technologies that provide employees with real-time actionable feedback messages for several reasons. Firstly, we show that feedback may have different effects on different types of behaviour, and different feedback effects can occur among different groups of workers performing different types of tasks in different work environment. Secondly, a parallel study (Bonvanie, Broekhuis, Janssen, Maeckelberghe, & Wortmann,

2020) showed that workers who are in poorer health at the start of the monitoring phase feel less autonomous in altering their behaviour while being monitored. This felt lack of autonomy may lead to an increase of negative feelings towards the employer and job. Thus, providing employees with self-management devices meant to monitor and self-regulate health-related work behaviour might have the anticipated positive health effects for certain groups of employees, while other groups of workers suffer from unforeseen negative health effects

Limitations

The first limitation was shortly addressed in the results section, being the low number of sitting events that we could include in the analyses to test the hypotheses. This low number of events was due to an incorrect setting in the generation of feedback, as a result of which feedback messages were sent to participants too late in response to their sitting events, which unfortunately was only noticed in the stored data after the end of the experimental period.

In the original study design, we also wanted to test whether self-controlled (versus externally imposed) feedback frequency would have linear behavioural effects rather than U-shaped curvilinear effects as reported by Lam (2011). In order to do so, a yoked control group was set up as a second cohort in this study. Unfortunately, technical errors in the transmission of feedback messages caused the time between follow-up messages to be different between the two cohorts. This made it impossible to compare both cohorts, so the second cohort was excluded from analysis.

The typing tool used a daily, static benchmark which was always measured in the same timeslot, viz. the first hour of the working day. However, the relevance of this benchmark might differ for workers who executed different computer tasks (with very different ways of typing) during the benchmark time window and the rest of the day. This static benchmark could have, for instance, affected the outcomes when during the benchmarking time window e-mails were answered and afterwards analyses were programmed. In future projects were similar tools are applied, we would recommend to use either a self-learning system that can detect the type of activity, or a function that the participant can use to disable feedback for a set amount of time, in order to prevent receiving multiple feedback messages when the participant already knows that the messages are being sent due to the difference in task.

The data from the smart chair was not confirmed using an activity monitor. Therefore, it could be that workers sat for longer periods of time on another chair, for instance in a meeting or when working from home, yet still they received messages that no deviations from the norm were found. These events were not registered, and were not included in the analyses, so the outcomes might deviate from reality due to this lack of insight in the full sitting behaviour of the participants.

Areas for future research

Previous studies show that the combination of actionable messages regarding sitting behaviour and practical tools such as sit-stand desks decreases the amount of long sitting events for workers, even though these messages were not real-time related to actual current behaviour (Larouche et al., 2018). We recommend further research to examine the effectiveness of combinations of real-time actionable feedback messages with practical tools such as sit-stand desks that enable workers to switch between sitting and standing.

From a workplace health promotion point of view, the long-term health of workers is the main goal of implementing sensor technologies in the workplace. Despite the fact that many workers know that their behaviour may harm their health in the long term, they still do not always seem to change this behaviour when they receive notifications. We have argued that employees are more likely to respond to feedback messages that make them aware of the immediate harmful performance effects of certain behaviours, such as mental fatigue that occurs during typing behaviour, in addition to long-term effects. More research, however, is needed on how feedback messages can be combined with information obtained from other sources to effectively facilitate healthy work behaviour in the workplace.

Future research may focus on examining how the effects of feedback provided by sensor technology devices can be strengthened by feedback information obtained from colleagues and leaders. Especially in case of felt trade-offs between short-term performance effects (e.g., meeting deadlines) and long-term health effects (e.g., mental and physical wellbeing) of certain work behaviours, the feedback given by leaders and colleagues is likely to impact the choices made by the worker. If leaders and colleagues consistently value deadlines over health, this is likely to affect the experienced pressure for a worker to do the same, which could cancel out the efforts of employers to facilitate worker self-regulation of healthy work behaviour through self-management sensor technologies.

Research can also examine how objective data obtained from sensor and intervention technologies can be used to design ergonomic workplaces and healthy work routines for workers, including those who mainly have to do their work while sitting. By using sensor and intervention technologies, workers may be stimulated to use sit-stand desks when doing sedentary work for a longer period of time, or they could be triggered to use meeting rooms that facilitate stand-up meetings. Other ways to prevent prolonged sitting behaviour of office workers may include strategic positioning of necessary office equipment, such as printers and coffee machines, in order for workers to walk more during the day.