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Published in:
Applied Ergonomics

DOI:
10.1016/j.apergo.2017.07.012

IMPORTANT NOTE: You are advised to consult the publisher's version (publisher's PDF) if you wish to cite from it. Please check the document version below.

Document Version
Publisher's PDF, also known as Version of record

Publication date:
2017

Link to publication in University of Groningen/UMCG research database

Citation for published version (APA):
Roossien, C. C., Stegenga, J., Hodselmans, A. P., Spook, S. M., Koolhaas, W., Brouwer, S., Verkerke, G. J., & Reneman, M. F. (2017). Can a smart chair improve the sitting behavior of office workers? *Applied Ergonomics*, *65*, 355-361. https://doi.org/10.1016/j.apergo.2017.07.012

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Download date: 16-05-2025

Applied Ergonomics 65 (2017) 355–361

Contents lists available at ScienceDirect

Applied Ergonomics

journal homepage: www.elsevier.com/locate/apergo

Can a smart chair improve the sitting behavior of office workers?

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ARTICLE INFO

Article history:
Received 22 March 2017
Received in revised form
11 July 2017
Accepted 21 July 2017
Available online 31 July 2017

Keywords:
Sedentary behavior
Smart sensor chair
Tactile feedback

ABSTRACT

Prolonged sitting can cause health problems and musculoskeletal discomfort. There is a need for objective and non-obstructive means of measuring sitting behavior. A ‘smart’ office chair can monitor sitting behavior and provide tactile feedback, aiming to improve sitting behavior. This study aimed to investigate the effect of the feedback signal on sitting behavior and musculoskeletal discomfort. In a 12-week prospective cohort study (ABCB design) among office workers ($n = 45$) was measured sitting duration and posture, feedback signals and musculoskeletal discomfort. Between the study phases, small changes were observed in mean sitting duration, posture and discomfort. After turning off the feedback signal, a slight increase in sitting duration was observed (10 min, $p = 0.04$), a slight decrease in optimally supported posture (2.8%, $p < 0.01$), and musculoskeletal discomfort (0.8, $p < 0.01$) was observed. We conclude that the ‘smart’ chair is able to monitor the sitting behavior, the feedback signal, however, led to small or insignificant changes.

1. Introduction

Office workers sit for long periods during their working hours (Thorp et al., 2012). Workers usually exceed recommendations regarding maximum time working in a sitting position (Netten et al., 2011; Goossens et al., 2012; Ryan et al., 2011). Prolonged sitting results in an increased risk of developing health problems (Healy et al., 2013; Chau et al., 2010) and musculoskeletal discomfort (Mathiassen, 2006; Hallman et al., 2016; Zemp et al., 2017). Due to the static character of sitting, the level of muscular tension may cause fatigue and, with insufficient recovery, can result in long-term health problems (Hamburg-van Reenen et al., 2008). To prevent these health problems, the sitting behavior of office workers must be improved (Thorp et al., 2012; Robertson et al., 2009; Straker et al., 2013).

To gain a more comprehensive insight into the sitting behavior of office workers, there is a need for objective and non-obstructive means of measuring sitting behavior (Thorp et al., 2012; van Uffelen et al., 2010; Netten et al., 2011; Wells et al., 2007). Sitting behavior can be measured with questionnaires and activity trackers (Robertson et al., 2008, 2009; Amick et al., 2012; Straker et al., 2013). Multiple studies have investigated the reliability of questionnaires for measuring sedentary behavior and have shown that self-reported measures are a valid way of assessing sedentary behavior (Clemes et al., 2012; Craig et al., 2003; Healy et al., 2011). However, questionnaires are based on self-reporting and therefore reflect the individual's own perceptions (Harvey et al., 2013; Clark et al., 2011), and do not provide detailed information about the actual sitting behavior (Cleland et al., 2014; Healy et al., 2011; Clemes et al., 2012). Activity trackers can be used to objectively measure sitting and standing duration (Robertson et al., 2009; Straker et al., 2013), but they cannot measure sitting postures (Netten et al., 2011; Healy et al., 2011). A measuring tool to provide more detailed patterns of sitting throughout the day is needed. (Zemp et al., 2016).

With a ‘smart’ office chair (*Axia Smart Chair*, BMA Ergonomics, Zwolle, the Netherlands) equipped with sensors located in the seat

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http://dx.doi.org/10.1016/j.apergo.2017.07.012

surface (4 sensors) and backrest (2 sensors), see Fig. 1, sitting behavior can be objectively monitored. Additionally, a tactile feedback signal (vibration) can be provided to the user if a set duration limit is reached. Application of this intervention in an eight-week pilot study appeared to shorten sitting duration and improve posture (van der Doelen et al., 2011; Netten et al., 2011), but the initial effects decreased over time (Goossens et al., 2012). None of these studies, however, tested for longer durations or controlled for the sitting duration, amount of activity away from the smart chair during working hours, or the effects of tactile feedback. Additionally, it is unknown if improved sitting behavior reduces health problems and musculoskeletal discomfort (Cascioli et al., 2016; Netten et al., 2011). These shortcomings were addressed in the present study.

In this study the smart chair and its feedback signal were further investigated and its effect on sitting behavior and musculoskeletal discomfort was explored. The aims of this study were to: (1) investigate the effect of the feedback signal on the sitting behavior, defined as sitting duration (30 and 60 min), posture and the dynamic (alternation between sitting and non-sitting and postures) and static components (sitting blocks and blocks of sitting in one posture) of sitting; (2) investigate the effect of the feedback signal on the perceived local musculoskeletal discomfort related to working while seated for a prolonged time; (3) investigate the difference between the measured sitting duration with the smart chair and behavior measured both in and out of the chair with an activity tracker (sitting duration and amount of steps).

2. Methods

2.1. Design

In this 20-week prospective cohort study, sitting behavior was monitored among the office workers of five companies. Based on the availability of materials, this study was performed in two cohorts of 24 and 25 subjects, respectively, between 2015 and 2016. For this study, the first 12 weeks were divided into four phases (ABCB design). Phase 1 (week 1; acclimatization): the Axia Smart Chair and the subject's workplace were adjusted according to ergonomic guidelines in dynamic interrelation, followed by one week of acclimatization (Goossens et al., 2012). Phase 2 (weeks 2–3; monitoring I): the subject's sitting behavior was monitored while the feedback signal was deactivated. Phase 3 (weeks 4–9; intervention): the feedback signal was activated and the subject's sitting behavior was monitored. Phase 4 (weeks 10–12; monitoring II): the feedback signal was deactivated and the subject's sitting behavior was monitored. In weeks 2 (begin monitoring phase I), 4 (begin intervention phase), 9 (end intervention phase) and 12 (end monitoring phase II), the subjects wore an activity tracker (Actigraph GT3X+, ActiGraph LLC, Fort Walton Beach, FL, United States) throughout the whole working week. On one specific day in weeks 2, 3, 9 and 12, the subjects received questionnaires by mail (at the beginning and end of their working day) about their experienced local musculoskeletal discomfort (LMD questionnaire of van der Grinten and Smitt, 1992), and the second cohort received two additional questionnaires in weeks 5 and 7 to gain further insight into the discomfort experienced during the intervention phase. The measurement scheme is presented in Table 1. Except for the additional questionnaire, all subjects followed the same protocol and received the same intervention.

Fig. 1. BMA Axia Smart Chair with label with sensor location. (BMA Ergonomics, 2017) *Single column fitting image.*

2.2. Subjects

The subjects were office workers recruited by distributing flyers within the selected companies, followed by an oral presentation to inform participants about the contents of the study. The companies were active in medical care, technical services, civil engineering, industrial cleaning and the petro chemistry industry. Inclusion criteria: the subjects worked at least three days a week, 5 h a day (37.5% of a working week), and had a personal workplace. Pregnant women were excluded due to the shift of their center of gravity (Casagrande et al., 2015). The Medical Ethics Committee of the University Medical Center Groningen, the Netherlands, issued a waiver for this study, stating that it does not involve medical research under Dutch law (M15.175675).

2.3. Material

2.3.1. Office chair

This study used the Axia Smart Chair developed by BMA Ergonomics (Zwolle, the Netherlands). This chair is a ‘regular’ office chair equipped with pressure sensors located in the seat surface (4 sensors) and backrest (2 sensors). The measuring interval was 1 s and the data, logged once per minute, included the most dominant posture and the related score for this time span. The data were collected using Axia Insight software (BMA Ergonomics, Zwolle, the Netherlands). In the output, eight postures were defined as follows: (1) optimal support (van der Doelen et al., 2011), (2) poor upper back contact, (3) poor lower back contact, (4) too much to the left, (5) too much to the right, (6) slouching, (7) edge of the chair and (8) not sitting. Feedback was provided based on an algorithm (BMA Ergonomics, Zwolle, the Netherlands) that accounted for sitting posture, duration and alternation between postures. Based on this score, a feedback signal was provided to the subject; a (vibration) feedback signal was given when the user demonstrated prolonged periods (30 or 60 min, standard 60 min) in unfavorable sitting postures and a low number of alternations (≤ 3 alternations in posture per 60 min) (Goossens, 2009) for more than a preset amount of time during the preceding hour (van der Doelen et al., 2011; Netten et al., 2011). The tactile feedback signal was located in the seat surface and consisted of four short pulses over 4 s. The subjects received the feedback signal and information about their sitting behavior was also available from a fixed tab attached to the seat of the chair. The user could activate this fixed tab themselves whenever they wanted. This fixed tab on the chair showed the current sitting posture, the most dominant sitting posture over the preceding half hour and the average score (between 1 and 5, with higher scores indicating more optimal sitting behaviors).

Table 1
Experimental planning: Materials used during this study per phase and week, x means used in this week. *2-column fitting image.*

	Phase 1: Acclimatization	Phase 2: Monitor I		Phase 3: Intervention						Phase 4: Monitor II		
Week number	1	2	3	4	5	6	7	8	9	10	11	12
Sitting behavior	X	X	X	X	X	X	X	X	X	X	X	X
Activity trackers		X		X					X			X
Physical discomfort questionnaire (group 1)		X	X						X			X
Physical discomfort questionnaire (group 2)		X	X		X		X		X			X

2.3.2. Questionnaire

Musculoskeletal discomfort was measured with the Localized Musculoskeletal Discomfort (LMD) questionnaire (van der Grinten and Smitt, 1992). The LMD is a reasonably reliable and sensitive method by which to measure localized musculoskeletal discomfort of low static musculoskeletal loads caused by static postures within subjects and groups (van der Grinten and Smitt, 1992; Hamburg-van Reenen et al., 2008). Subjects rated the following five body areas on perceived LMD at the beginning (9:00) and end (15:00) of the working day on specific days (see Table 1): (1) forearms and hands, (2) neck, shoulders and upper arms, (3) upper back, (4) lower back, (5) buttocks and legs. The first cohort (companies 1, 2 and 3) received this questionnaire at the beginning of the monitoring phase and at the end of the monitoring, intervention and monitoring II phases (week numbers 2, 3, 9 and 12). The second cohort (companies 4 and 5) received an additional LMD questionnaire in weeks 5 and 7 in the intervention phase to gain more insight regarding that phase. Ratings could vary from 0 to 10 (Borg scale, in increments of 0.5), with 0 indicating no discomfort, 0.5 indicating extremely little discomfort and 10 indicating extreme discomfort (almost maximum). An invitation to the questionnaires were send 15 min before 9 or 15 h to the subjects by mail, If the questionnaire was not completed within about 1 h after receiving the invitation, a reminder was send. Each questionnaire was available for 2.5 h.

2.3.3. Activity tracker

The activity tracker Actigraph GT3X+ (ActiGraph LLC, Fort Walton Beach, FL, United States) was used to measure when the participant was not sitting on the smart chair (sitting, standing and walking). This activity tracker has been proven capable of reliably detecting sitting, standing and walking in daily life (Kooiman et al., 2015; Aguilar-Farías et al., 2014). In total, 38 subjects received an activity tracker due to limited availability. These subjects were selected based on gender, age and the company they were working to create a representative group of the subjects.

2.6. Data analysis

From the ‘smart’ chair the sitting duration and sitting postures were obtained per working day and phase. Sitting duration and posture were split up into 6 parameters containing a static and dynamic component. The sitting duration was expressed in (1) sitting duration; (2) static sitting blocks (of >30 min and >60 min); (3) dynamic alternation between sitting and non-sitting. Sitting postures was expressed in (4) sitting in an optimal supported posture; (5) static sitting blocks in one posture (>15 min); (6) dynamic alternation between sitting postures. Non-sitting was defined as not sitting in the ‘smart’ chair and could be standing (sit/stand desk) or walking or sitting on another chair. From the activity trackers was calculated; (1) amount of steps; (2) sitting duration. The data of the activity tracker was linked to the sitting duration of the ‘smart’ chair. From the LMD questionnaire was calculated: (1) the overall discomfort score; (2) discomfort score per body part.

For statistical analysis, only workdays with more than 60 min of sitting were included. The same holds for wearing the activity tracker more than 60 min. Since the duration of the working days differed across subjects and days, all data were equalized by converting the data to an eight-hour working day for statistical analysis. This was done by converting the percentage of work time into an eight-hour working day. For example a working day of 7 h with a sitting duration of 60.0% was converted to a working day of 8 h with a sitting duration of 68.6% (= (60.0%/7 h) x 8 h).

To test the research questions, a paired *t*-test was used for normally distributed data. For non-normally distributed data, the non-parametric Friedman test was used. For all parameters, difference between the phases were tested; phase 1 versus 2, phase 2 versus 3, phase 3 versus 4 and phase 2 versus 4. Differences with p-values <0.05 were considered statistically significant. Parameters were given for the t-tests together with their standard error of mean, and for the Friedman test with chi-square ($\chi2$) (degrees of freedom). The tests were performed using SPSS (IBM SPSS Statistics 24, New York, United States). Missing data from the LMD questionnaire and activity trackers were not imputed and analyzed with listwise deletion. Sensitivity analyses were performed to test differences between participants with complete and incomplete data sets.

3. Results

3.1. Sitting behavior in chair

Forty-nine office workers participated in this study (20–65 years of age). Three subjects prematurely ended their participation during or at the end of the intervention phase due to reorganization, absence due to (long-term) illness and a new job at another company. One subject had technical issues with the sensor chair. These four subjects did not provide complete data sets and therefor were not included, resulting in a study group of 45 subjects (19 males, 26 females) with a mean age of 43.1 ± 11.0 years (mean ± SD).

Over the 12-week study period, the subjects were present at their own workplace about 3.6 days per week, resulting in 1948 days of data gathered with the smart chair. In Table 2, we present these subjects' sitting behavior per phase (duration of working day in hours), expressed in (1) sitting duration, (2) sitting blocks of more than 30 and 60 min, (3) alternation between sitting and not sitting, (4) sitting in an optimally supported posture, (5) sitting blocks of more than 15 min in one posture, and (6) alternation between sitting postures. Changes in mean sitting duration between all phases were small and insignificant ($p > 0.228$) except between the intervention and monitoring phase II of sitting blocks of more than 60 min ($p = 0.007$, $t(44) = 2.804$). During monitoring phase II, a decrease in sitting in an optimally supported posture was observed ($p = 0.001$, $\chi2(3) = 16.684$), as compared to the intervention phase ($p = 0.000$, $\chi2(1) = 22.348$) and monitoring phase I ($p = 0.011$, $\chi2(1) = 6.422$). The other parameters did not change significantly over the phases ($p > 0.16$). All working days longer

Table 2
Sitting behavior per phase: The mean sitting behavior (n = 45) measured with the ‘smart’ chair and activity tracker. All data is the mean with standard deviation (mean ± SD) per working day per phase. *2-column fitting image*.

	Parameters	Acclimatization	Monitoring I	Intervention phase	Monitoring II	Average
Sedentary behavior (activity tracker)	Duration of working day (h)	7.5 ± 1.5	7.9 ± 0.8	7.7 ± 1.0	7.6 ± 1.0	7.7 ± 1.1
	Steps (counts)	–	3226 ± 1092	3061 ± 1331 2996 ±1522	2899 ± 1357	3033 ± 1333
	Sitting duration (%)	85.9 ± 8.7 (6.9 h)	89.1 ± 4.4 (7.1 h)	89.6 ± 4.9 (7.2 h)	90.4 ± 4.2 (7.2 h)	88.8 ± 6.0 (7.1 h)
Sitting duration (smart chair)	Sitting duration (%)	66.3 ± 14.5 (5.3 h)	67.0 ± 10.1 (5.4 h)	67.9 ± 10.8 (5.3 h)	65.8 ± 10.8 (5.2 h)	66.7 ± 11.1 (5.3 h)
	Sitting blocks of >30 min (counts)	3.6 ± 1.3	3.8 ± 1.0	3.8 ± 0.9	3.7 ± 1.2	3.7 ± 1.1
	Sitting blocks of >60 min (counts)	1.5 ± 1.0	1.5 ± 0.7	1.5 ± 0.7	1.3 ± 0.6	1.4 ± 0.8
	Alternation between sitting vs non sitting (counts)	13.7 ± 6.3	13.8 ± 6.7	13.9 ± 6.3	13.8 ± 6.8	13.8 ± 6.5
Sitting posture (smart chair)	Sitting in optimal supported posture (%)	12.4 ± 13.6	14.1 ± 14.6	14.0 ± 15.6	11.2 ± 13.7	12.9 ± 14.3
	Sitting blocks of >15 min in one posture (counts)	3.5 ± 3.6	3.4 ± 3.3	3.3 ± 3.0	3.2 ± 2.9	3.3 ± 3.2
	Alternation between sitting postures (counts)	95.4 ± 33.3	95.3 ± 33.2	97.5 ± 28.9	94.7 ± 31.4	95.7 ± 31.5

than 60 min were included in the analyses. With sensitivity analyses, the results of working days longer than 20 min of sitting instead of 60 min were investigated. The same or similar ($\leq$0.3% change) results were also found for changes within phases.

During the intervention phase, 796 feedback signals were provided to the subjects. The subjects received, on average, 0.8 ± 0.8 feedback signals per working day. In the last week of the intervention phase, a significantly greater number of feedback signals were provided ($p = 0.037$, $\chi2(1) = 4.333$). When comparing those subjects who received very low numbers of feedback signals (on average less than one signal a day) ($n = 26$) to the subjects who received more than one feedback signal a day ($n = 19$), it was found that these subjects were significantly more regularly sitting in an optimally supported position (20.2% ± 17.3 compared to 5.5% ± 6.5 (mean ± SD).) ($p = 0.000$, $\chi^2(1) = 16.173$). The other parameters presented in Table 2 did not change or differ significantly.

3.2. LMD

The average LMD score was 1.0 ± 1.2 during this study. Fig. 2 shows a significant decrease ($p = 0.008$, $\chi^2(3) = 11.943$) in experienced discomfort during monitoring phase II ($p = 0.001$, $\chi^2(1) = 11.645$). Sitting in an optimally supported posture significantly decreased during monitoring phase II ($p = 0.001$, $\chi^2(2) = 14.247$), as compared to monitoring phase I ($p = 0.019$, $\chi^2(1) = 5.538$) and the intervention phase ($p = 0.000$, $\chi^2(1) = 12.462$).

Fig. 3 shows the LMD score per region. All group level changes are small, and most are insignificant. However, lower back discomfort decreases significantly during monitoring phase I ($p = 0.050$, $\chi^2(1) = 3.846$) and increases during the intervention phase ($p = 0.041$, $\chi^2(1) = 4.172$). Discomfort in the buttocks and legs decreases significantly in monitoring phase I ($p = 0.046$,

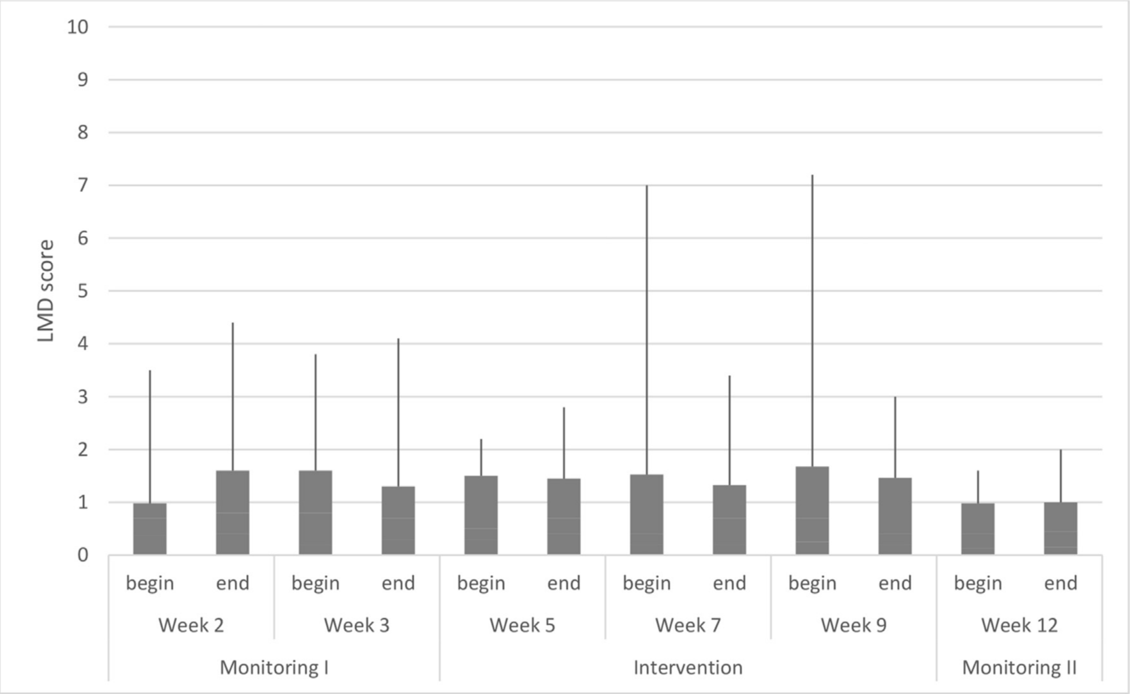

Fig. 2. Local Musculoskeletal Discomfort (LMD): Mean overall LMD score with standard deviation per week at the begin and end of measuring day (n = 22). *2-column fitting image.*

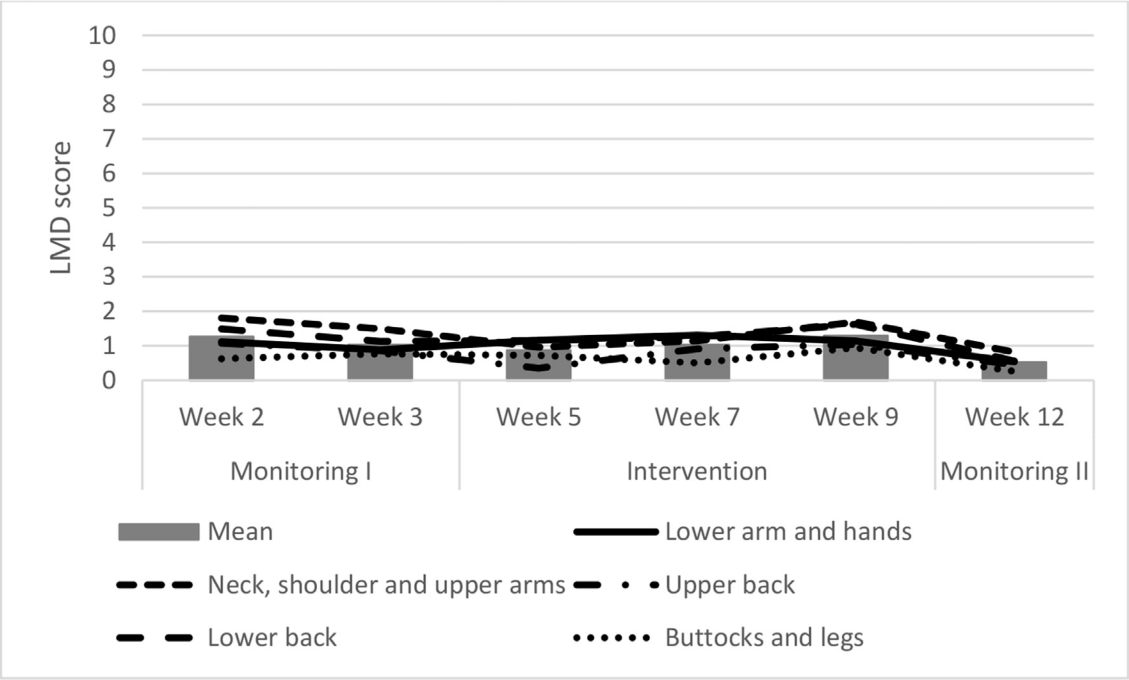

Fig. 3. Local Musculoskeletal Discomfort (LMD) per body region: Mean LMD score per body region per phase (n = 22). *1.5-column fitting image.*

$\chi^2(1) = 4.000$). Discomfort in all regions decreases significantly ($p = 0.000$, $\chi^2(29) = 65.822$) during monitoring phase II, except for the upper back: lower arms and hands ($p = 0.008$, $\chi^2(1) = 7.143$); neck, shoulders and upper arms ($p = 0.001$, $\chi^2(1) = 11.842$); lower back ($p = 0.001$, $\chi^2(1) = 11.560$); buttocks and legs ($p = 0.005$, $\chi^2(1) = 8.067$).

Overall, 21 subjects did not complete one or more questionnaires. In total, 37.4% of the LMD questionnaires were completed. For sensitivity analyses, the sitting behavior of the respondents who completed the LMD questionnaires was compared to the sitting behavior of all subjects. The results were the same or somewhat improved: sitting duration, 1.2–2.0%; sitting in optimally supported posture, 1.1–2.3%; sitting block during monitoring phase II, 0.5; alternation between sitting postures, 1.1 to 5.1. These changes were not significant as compared to all subjects, and the same significant changes in sitting behavior between the phases were found. The subjects who did not fill in the questionnaire were 43.6 ± 10.7 years (mean ± SD) of age and 57.1% female.

3.3. *Sitting behavior in- and outside chair*

38 subjects received an activity trackers (18 males, 20 females) with a mean age of 43.9 ± 10.8 years (mean ± SD). The activity trackers were worn 70.1% of the total time during this study. According to the chair data, the subjects spent, on average, 67.0% of their time in a sitting position. Adding sitting duration away from the smart chair showed that the subjects were sitting 88.8% of the working day. The sitting duration increased slightly and insignificantly ($p \geq 0.07$) between the acclimatization phase, monitoring phase I and intervention phase, and decreased during monitoring phase II. The activity tracker showed an increase in sitting duration during monitoring phase II ($p = 0.007$, $\chi^2(3) = 12.231$), as compared to the baseline ($p = 0.011$, $\chi^2(1) = 6.533$) and the intervention phase ($p = 0.040$, $\chi^2(1) = 4.235$). In line with this finding, an insignificantly decreasing trend in the number of steps taken is shown between monitoring phase I and monitoring phase II ($p = 0.054$, -293.7 ± 801.3, [-592.9;5.5]). For sensitivity analyses, the sitting behavior of the subjects who wore the activity tracker was compared to the sitting behavior of all subjects. The same or comparable results (changes ≤1.6%) were found with no significant changes.

4. Discussion

In this study is show that it is possible to monitor the sitting behavior of office workers for long durations using a smart chair. During the intervention phase, sitting behavior did not change significantly. After turning off the feedback signal, the subjects sat for longer periods of time and less often in an optimally supported posture. The experienced discomfort did not decrease during the intervention phase. After turning off the feedback signal, the amount of experienced discomfort decreased. A temporal effect of sitting behavior on musculoskeletal discomfort could not be proven. The subjects were sitting for about 89% of the whole day and at the workplace in the smart chair for approximately 67% of the working day. We had expected a decrease in sitting duration, sitting blocks and LMD score, an increase in amount of alternations of sitting postures, and alternation between sitting vs non sitting, amount of steps in the intervention phase compared to monitoring phase I and II. This was, however, not observed. Thus, an effect of feedback signal on sitting behavior was not observed, which lead to the conclusion that the feedback signal improved neither sitting behavior nor discomfort. The feedback aimed to increase the duration sitting in an optimal supported posture with the common belief to lower the musculoskeletal discomfort, however nor research to support this in a clinical setting. Some observed changes achieved statistical significance, yet these changes were small and their relevance is unclear. The results show large SD indicating large difference between subjects and a non-homogenous sample. The inter-individual differences are probably responsible for the small, but significant changes. Given these minimal changes, a temporal effect of sitting behavior on musculoskeletal discomfort is unlikely, as is an effect of the feedback signal on experienced local musculoskeletal discomfort related to prolonged sitting work. A slight improvement in sitting behavior and LMD at the beginning of the intervention phase was observed, but this change was not a significant or retentive effect, and the response rate for the questionnaire was very low.

Our findings may be indicative of no effect. There are, however, alternative explanations for our observations in this study. Differences in study design compared to others (Netten et al., 2011; Goossens et al., 2012) were that the workplaces of the subjects were adjusted according to ergonomic guidelines where necessary, and at least one week was set aside for subjects' acclimatization to their adjusted workplace to eliminate the effect of this factor. This may explain a smaller effect of the present study. One other explanation for our findings could be the low feedback frequency, which resulted in a low number of feedback signals provided to the subjects. Half of the subjects received a very low number of feedback signals (less than one feedback signal a day), indicating a naturally good sitting posture with a small improvement range (floor effect). This is also the case for perceived local musculoskeletal discomfort. The average and starting LMD score was low, resulting in a minimal improvement range. Moreover, the response rate for the LMD questionnaires was low, with a random rather than systematic bias. Besides, a few subjects mentioned that they had performed an activity that was not chair- or work-related, like sport, which could have caused an increase in the LMD results during the intervention phase. The LMD questionnaire was taken once per phase (twice a day) for the first group. The remarkable results were the increase in sitting duration and decrease in optimally supported posture sitting during monitoring phase II versus the decrease in experienced musculoskeletal discomfort. The difference between the sitting duration in the chair (5.4 h) and out of the chair (7.1 h) is consistent with existing literature (Netten et al., 2011), demonstrating the need for an additional measure to capture all sitting (in multiple chairs) during a full day.

The strengths of this study are that this research was performed for the same or a longer period than other research regarding the smart chair, and experienced musculoskeletal discomfort was taken into account and related to the feedback signal. In addition, this study was performed in a real-life working environment of five different companies with office workers with diverse jobs. Moreover, an activity tracker was used to provide insight into sitting behavior away from the smart chair (e.g., during meetings or appointments outside the office) to get more detailed information about the subject's sitting behavior over the working day. In addition, in this research, multiple parameters of sitting behavior were used. Usually, research is performed regarding one parameter of sitting behavior, such as sitting duration (Clark et al., 2011; Clemes et al., 2012; Dunstan et al., 2012; Hallman et al., 2016; Healy et al., 2011, 2013) or (alternation of) sitting postures (Amick et al., 2012; Grooten et al., 2017; Mathiassen, 2006). Only a few studies have included multiple parameters of sitting behavior (Netten et al., 2011; Mathiassen, 2006; Goossens et al., 2012). A limitation of this study is that, although the subjects received instruction not to adjust the chair, at least six subjects did adjust the chair during the 12-week study. Depending on the type of adjustment, this could have influenced the outcomes. Based on a small lab study and instructions of the manufacture, in line with research of Netten et al. (2011), van der Doelen et al. (2011) and Goossens et al. (2012), the working of the chair is most optimal when it was installed according to ergonomic guidelines. Adjustments can cause no or less contact with the sensors resulting in incorrect detection of the sitting posture. Besides, not allowing making adjustment to the chair is creating an unnatural situation which was necessary to ensure that potential effect were due to the intervention and not caused by adjustment of the chair. Furthermore, the data were converted into an eight-hour working day, and this extrapolation could have influenced the results. In addition, there could be a difference between the two cohorts due the period of measurement; the first cohort was measured from September 2015 to January 2016 while the second cohort was measured from February 2016 to June 2016. The influence of this difference on the outcome is unknown. Moreover, while this study explored differences between subgroups (amount of alternation in sitting posture) and task-related trends, it was underpowered for these sub analyses.

Insight regarding the parameters of the sitting behavior of office workers is gained in this study. There is a knowledge gap with regard to, in particular, the alternation between sitting and standing, different sitting postures and movements on the chair (Lin et al., 2017; Claus et al., 2016; Cascioli et al., 2016; Mathiassen, 2006). A smart chair could be a useful non-obstructive tool by which to gain greater insight into the sitting behavior of office workers, its patterns and its parameters. This information is necessary to make office workers aware of their own sitting behaviors and to develop a comprehensive definition of healthy sitting behavior. While health risks related to sitting are well studied (Dunstan et al., 2012; Thorp et al., 2012; van Uffelen et al., 2010), there is no agreed definition of healthy sitting behavior. Since clear guidelines are unavailable (Dunstan et al., 2012; Healy et al., 2013), healthy sitting guidelines should probably contain a combination of duration and posture, indicating that duration should not exceed 20 or 30 min, and posture should include 'dynamic sitting', referring to alternation of sitting postures (Mathiassen, 2006; Thorp et al., 2012; Hallman et al., 2016). With this definition, sitting behavior could be more efficiently improved and sitting-related health problems could be prevented.

In future research, the moments of feedback signal provision to the user must be further investigated. The parameters behind the feedback signal are probably a good reflection of the sitting behavior, but increasing the feedback frequency and adding another kind of feedback, such as visual or combination feedback, could be more effective. Furthermore, subjects with health complaints and musculoskeletal discomfort must be included. Future studies might use the results of this study to answer targeted study questions. In addition, coupling an activity tracker and the chair to a single platform would create a more complete representation of the subject's sitting behavior over the whole day, including the amount of activity away from the chair. Moreover, with data per second it is possible to measure movements on the chair alongside shifts in posture, which could provide more detail regarding sitting patterns.

5. Conclusion

The results of this study show that tactile feedback did not cause significant changes in the sitting behavior and musculoskeletal discomfort of office workers.

Funding

This study, part of SPRINT@Work, is part-financed by the European Regional Development Fund, the province and municipality of Groningen, and the province of Drenthe [grant number T-3036, 2013]. BMA Ergonomics has supplied 24 Axia Smart Chairs during this study.

Disclosures

The 'smart' chairs used in this study were borrowed from BMA Ergonomics during performance of this study. BMA Ergonomics may potentially benefit from the research results, depending on the outcomes. Any findings, and conclusions or recommendations presented in this article are those of the author(s) and do not necessarily reflect the views of BMA Ergonomics. There is no conflict of interest.

Acknowledgements

We would like to thank BMA Ergonomics for providing the *Axia Smart Chair* during this experiment, particular Bas van der Doelen for his support and advice.

We would like to thank Martijn de Groot of Quantified Self Institute of the Hanze University of Applied Sciences, Groningen, The Netherlands for his support during this study.

Any findings, and conclusions or recommendations presented in this article are those of the author(s) and do not necessarily reflect the views of BMA Ergonomics.

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