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Low back pain and its relationship with sitting behaviour among sedentary office workers

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ABSTRACT

The relationships between sedentary lifestyle, sitting behaviour, and low back pain (LBP) remain controversial. In this study, we investigated the relationship between back pain and occupational sitting habits in 64 call-centre employees. A textile pressure mat was used to evaluate and parameterise sitting behaviour over a total of 400 h, while pain questionnaires evaluated acute and chronic LBP.

Seventy-five percent of the participants reported some level of either chronic or acute back pain. Individuals with chronic LBP demonstrated a possible trend (*t*-test not significant) towards more static sitting behaviour compared to their pain-free counterparts. Furthermore, a greater association was found between sitting behaviour and chronic LBP than for acute pain/disability, which is plausibly due to a greater awareness of pain-free sitting positions in individuals with chronic pain compared to those affected by acute pain.

1. Introduction

Today, sedentary lifestyle has become omnipresent, as an increasing number of individuals spend extended periods in a seated position at work as well as during leisure time (Jans et al., 2007; Saidj et al., 2015; Hadgraft et al., 2015). Simultaneously, the prevalence of low back pain (LBP) has increased among office workers in general (Ayanniyi et al., 2010; Collins and O'Sullivan, 2015). Specifically, call-centre employees have recently become the focus of attention in this field as they spend up to 95% of their total work time in a seated position (Toomingas et al., 2012), but their jobs are also recognised for potentially high levels of stress, especially when dealing with difficult or aggressive customers (Johnson et al., 2005; Oh et al., 2017). Since high job-related stress is additionally thought to be related to musculoskeletal disorders of the lower back (Sprigg et al., 2007), it is therefore unsurprising that a higher proportion of call-centre workers report musculoskeletal symptoms than other professional office users (Norman et al., 2004).

Since LBP represents the third leading cause of self-perceived disability due to various diseases (Vos et al., 2016) and indicates a major economic burden to society (Wieser et al., 2011; Nöllenheidt and Brenscheidt, 2016), identifying risk factors, especially within the office environment, appears to be of high importance for implementing suitable prevention programs.

While it might be expected that LBP and sedentary office work are highly related, the literature offers only little evidence. On the one hand, recent studies report that seated working periods of longer than 7 h per day significantly increase the risk of LBP (Odds Ratio = 1.89) (Cho et al., 2012; Subramanian and Arun, 2017). On the other hand, several systematic reviews have failed to prove that sitting duration on its own is linked to the onset of LBP and found no significant association between sitting itself and the risk of LBP in office workers (Chen et al., 2009; Lis et al., 2007; da Costa and Vieira, 2009; Bakker et al., 2009; Kwon et al., 2011; Hartvigsen et al., 2000). This lack of evidence is assumed to mainly result from the multifactorial nature of LBP, as well as from possible methodological weaknesses, including unreliable subjective measurement instruments, low measurement durations, and low number of subjects in the scientific literature (Kwon et al., 2011; Hartvigsen et al., 2000), which complicate the establishment of any causal relationships (Hoy et al., 2010).

Even though associations between sitting duration and LBP seem to be controversial, other aspects of sitting behaviour might have critical links to LBP among office workers. Here, Womersley and May (2006) reported that individuals with pain sat uninterrupted for longer periods and showed a more flexed and relaxed sitting posture than pain-free individuals, suggesting that individual sitting habits may be related to LBP, even if the causal links are unclear. Despite several investigations

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into "perfect" sitting positions in terms of the "optimal" spinal curvature during sitting (Waongenngarm et al., 2015; O'Sullivan et al., 2012a; Pynt et al., 2001; Baumgartner et al., 2012; Zemp et al., 2013), broad consensus is lacking, suggesting that the "correct" sitting position might be subject-specific (Claus et al., 2016). Moreover, Claus et al. (2009) proposed that any sustained sitting posture could result in fatigue, discomfort and pain, suggesting that a "good" posture could still be detrimental if it persists uninterrupted for extended periods (Coenen et al., 2017). As a result, postural variability as well as regular small movements are plausibly beneficial for the prevention of LBP (Davis and Kotowski, 2014; Vergara and Page, 2002; Pynt et al., 2001; Srinivasan and Mathiassen, 2012; Aarås et al., 2000).

Dynamic sitting behaviour is thought to provide beneficial biological and physiological effects, since postural variations can reduce spinal loads (Davis and Kotowski, 2014) and spinal shrinkage (van Deursen et al., 2000), prevent muscle fatigue through alternating motor unit activation (van Dieën et al., 2001), and inhibit damage to the posterior aspect of the annulus pulposus by means of low magnitude dynamic movements (Callaghan and McGill, 2001). Moreover, Straker and Mathiassen (2009) indicated that short periods of inactivity can already cause local changes regarding biomechanical, physiological and neurological capability. It therefore appears reasonable that less dynamic sitting habits may result in discomfort and pain, especially in the lower back.

In previous studies, different measurement technologies such as video analysis (Womersley and May, 2006), accelerometers (Ryan et al., 2011), optoelectronic motion analysis (Dunk and Callaghan, 2005), force sensors (Yamada et al., 2009; Zemp et al., 2016b) and pressure distribution sensors (Zemp et al., 2016a) have all been used to assess sitting behaviour. Here, pressure distribution sensors offer a relatively cheap measurement approach that neither disturbs nor affects the subject during measurement, and allows high accuracy for classifying individual sitting behaviour and positions (Zemp et al., 2016a; Kamiya et al., 2008). Additionally, pressure mats are easily attachable and therefore offer a practical solution for analysing the sitting behaviour of participants on their own chair.

A previously conducted pilot study ($N = 20$) demonstrated tendencies towards a more static sitting behaviour in participants with mild LBP (Zemp et al., 2016a). Towards gaining a deeper understanding of the relationships between LBP and occupational sitting habits, the goal of this study was to build on the previous pilot data and establish whether call-centre employees with LBP express different sitting behaviour patterns from those without LBP.

2. Methods

2.1. Participants

Since the working task is known to strongly impact on sitting behaviour (van Dieën et al., 2001; Dunk and Callaghan, 2005; Ellegast et al., 2012; Groenesteijn et al., 2012; Grooten et al., 2017), this study selected a large number of participants that worked in an environment with highly standardised working tasks. Furthermore, in order to maintain real-world validity, no additional work assignments, or sitting/movement instructions were provided to the participants during the measurement period. Therefore, seventy office workers from a professional call-centre company located in Dresden and Leipzig (Germany) were recruited. Participants were required to speak German and were excluded if they were pregnant, took glucocorticoids, or were currently undergoing medical treatment for other physical complaints besides back pain. All participants provided written informed consent prior to participation in this study, which was conceptualised and performed in accordance with the principals of the declaration of Helsinki and was approved by the ethics committees of the University Potsdam, Germany (no. 42/2014) and confirmed by the ethics commission of ETH Zürich, Switzerland. After measurement completion, all participants received 15 Euros compensation and were provided with their individual study results.

2.2. Study environment

The call-centre environment offers a contemporary office work setting with regard to job assignments and physical organisation. Our selected call-centre specifically dealt with difficult and challenging customer situations, and it was therefore assumed that participants were exposed to a considerable mental stress burden (Johnson et al., 2005; Oh et al., 2017). The employees' work tasks were highly standardised, comprising typing at a computer and calling clients using a head-set, with nearly all duties undertaken in a sitting position. Since the company's work policy required a change of workplace every 3 h, it was not possible to ergonomically adjust the office desk and computer set-up to the individual requirements and preferences.

2.3. Study design

This study was conducted within 2 weeks at two different worksites of the call-centre company and each participant was assessed during one complete working shift. In order to investigate the true relationships between daily sitting behaviour and LBP, it was essential that the measurements were based on each subjects' real-world performance in the natural office environment, with participant's each using their own office chair, undertaking their own daily office tasks. The company provided three different office chair models, which all allowed adaptation of seat height and depth, as well as the option to fix the backrest at a certain angle or allow dynamic reclination. After measurement system set-up, data was collected for the entire working shift, including breaks. At the end of the working day, calibration measurements for the classification of the different sitting positions were performed. Similarly to the preceding pilot study (Zemp et al., 2016a), participants were asked to sit four times in seven predefined sitting positions: upright (P_1), reclined (P_2), forward inclined (P_3), laterally tilted right/left (P_4/P_5), crossed legs right over left/left over right (P_6/P_7). Afterwards the participants were asked to fill out the questionnaire (section 2.5).

2.4. Measurement systems

In order to assess sitting behaviour, spatio-temporal changes in the distribution of pressure across the participants' sitting interface were monitored by means of the textile pressure mat "sensomative science" (sensomative GmbH, Rothenburg, Switzerland) consisting of a 196 (14×14) sensor matrix with a size of 45 cm × 45 cm (www.sensomative.com). The pressure data were recorded at 1.5 Hz with a resolution of 8 bits and a maximum pressure limit of 60 kPa. Using Bluetooth Low Energy, the data were transferred from the textile mat to a connected mobile phone (Nexus 5X, Google, LG, Seoul, Korea) where the data were stored in the corresponding mobile phone application. In order to prevent the mat from sliding, the system was laterally fixed with two textile straps and belt loops (Fig. 1). Due to the pressure mats' thin and flexible nature, participants were not able to feel its presence.

2.5. Questionnaires

In order to gather information about short- and long-term pain status, including corresponding functional limitations, as well as sociodemographic information, the following standardised questionnaires were used:

2.5.1. Chronic Pain Grade questionnaire

To assess pain intensity and pain related functional limitations in the previous three months, participants were requested to complete the Chronic Pain Grade (CPG) questionnaire (Von Korff et al., 1992), which is divided into two subscales: (1) Korff characteristic pain intensity

Fig. 1. Textile pressure mat (sensomative science) fixed with two textile straps and belt loops at the seat pan of an office chair.

(*CPI*) and (2) Korff disability (*DISS*). Each CPG item ranged from 0 ("no pain/impairment") to 10 ("worst possible pain"/"I wasn't able to do anything"). For data analysis, items of each subscale were presented on a scale ranging from 0 to 100. Missing or inconsistent data were treated according to the CPG recommendations.

2.5.2. German brief pain inventory

The Brief Pain Inventory (BPI) (Radbruch et al., 1999) was used to estimate subjects' acute LBP within the previous 24 h. Similar to the CPG questionnaire, the BPI is subdivided into two subscales: (1) pain severity ($BPI_{Severity}$) and (2) pain-related interference ($BPI_{Interfere}$) of daily functions. Answering possibilities for the BPI ranged from 0 ("no pain"/"no interference") to 10 ("pain as bad as you can imagine"/"interferes completely") (Daut et al., 1983). The BPI also included a body chart to illustrate each participant's pain area(s), which allowed confirmation (or otherwise) of pain in the lower back region. Missing or inconsistent data were treated according to the BPI recommendations.

2.6. Data analysis

Data processing and analysis was performed similarly to the pilot study of Zemp et al. (2016a), which is only briefly described below:

2.6.1. Low back pain

The four pain variables (CPI, $DISS$, $BPI_{Severity}$, $BPI_{Interfere}$) were used to allocate participants into either subgroup A: no pain; no functional disability, or into subgroup B: with pain; with functional disability. Thereby, all participants with scores of 0 were allocated to subgroup A and all participants with scores greater than 0 were assigned to subgroup B.

2.6.2. Sitting position classification and validation

Raw pressure data were analysed using MATLAB (R2017a MathWorks Inc., Natick, USA). The random forest classification approach was applied to determine the sitting position of each subject at any instant during the entire working day (Zemp et al., 2016a, 2016b). The calibration measurements of all participants were used to create one general random forest classifier. Here, all pressure values of every calibration measurement were normalised to the maximal value of the 196 sensors, and an ensemble of 500 decision trees was used while all other parameters were kept at MATLAB's default levels.

In order to quantify the reliability of the sitting position classifier within this study, a leave-one-out (LOO) cross-validation was performed. Here, the calibration measurements of all participants except one was used as training data and the remaining measurement was used for validation. The classified sitting positions were then identified as correct or incorrect. This procedure was repeated for every calibration measurement in order to quantify the overall classification accuracy.

2.6.3. Participant sitting behaviour

In order to identify transient periods (when participants showed small body movements or moved from one sitting posture to another), firstly, raw pressure data were filtered using a zero-phase low-pass filter (1st order Butterworth filter, cut-off frequency: 0.2 Hz). A threshold value was then calculated for every participant, which was defined as 0.35% of the 93rd percentile of the pressure values throughout the working day. Finally, if more than two-thirds of the loaded sensors exhibited a higher differential in the pressure values from one time point to the next than the defined threshold value, these time points were considered as transient periods. In cases where the time between two transient periods was shorter than 3 s, the two transient periods were considered as one longer transient period. Remaining phases without transient periods were defined as stable sitting. Using the previously created random forest classifier, the specific sitting position was calculated 1 s after the onset of a stable sitting period and allocated to the whole stable period. In order to quantify sitting behaviour, four parameters were defined:

$\boldsymbol{N_{\hat{move}}}$: Mean number of movements per working hour, characterised by the number of transient periods during the whole working day divided by the number of working hours

$\boldsymbol{N_{\hat{pos}}}$: Mean number of positional changes per working hour, calculated as the number of sitting position changes during the whole working day divided by the number of working hours

$\boldsymbol{t_{\hat{stable}}}$: Mean time period of stable sitting, characterised by the mean length of stable sitting periods over the whole working day

$\boldsymbol{P_{transient}}$: Percentage of transient periods during the whole working period

2.6.4. Statistical analysis

Data management and statistical analysis were carried out using the software suite IBM SPSS Statistics (v24, SPSS Inc., Chicago, USA). In order to summarise the four sitting behaviour parameters ($\boldsymbol{N_{\hat{move}}}$, $\boldsymbol{N_{\hat{pos}}}$, $\boldsymbol{t_{\hat{stable}}}$, $\boldsymbol{P_{transient}}$) to one general parameter (*SitBePar*), a Principal Component Analysis (PCA) was conducted. Here, a FACTOR analysis with the correlation matrix method was used to extract the principal components, as well as to calculate *SitBePar* using a least squares regression approach.

After verifying normally distributed data by means of the Shapiro-Wilk-test, the influence of different characteristics of pain (CPI, $DISS$, $BPI_{Severity}$, $BPI_{Interfere}$) on the overall sitting behaviour (*SitBePar)* was analysed using two-tailed independent t-tests. In a second step, the same tests were applied for the pain groupings with the lowest p-values and for $\boldsymbol{N_{\hat{move}}}$, $\boldsymbol{N_{\hat{pos}}}$, $\boldsymbol{t_{\hat{stable}}}$, and $\boldsymbol{P_{transient}}$ in order to quantify the influence of the pain variables on the four individual sitting behaviour parameters.

3. Results

3.1. Participants

This study included 70 call-centre employees, from which six participants (8.6%) were excluded due to participation withdrawal ($N = 2$) or incomplete data sets of the measured pressure distribution ($N = 4$), resulting in a study sample of 64 participants (43 ± 13 years; 78 kg ± 21 kg; 170 cm ± 10 cm; 40 females). Furthermore, two subjects could not be included for analysis of the CPI and $BPI_{Severity}$ due to inconsistent and/or missing entries resulting in a total of 62 participants for the CPI and $BPI_{Severity}$, and a total of 64 participants for the $DISS$ and $BPI_{Interfere}$ grouping variable.

3.2. Low back pain

The two subscales of the CPG and BPI questionnaires showed good internal consistencies with Cronbach's alpha values of 0.92 (CPI), 0.92 ($DISS$), 0.94 ($BPI_{Severity}$) and 0.92 ($BPI_{Interfere}$). Overall, the majority of participants reported some level of either chronic or acute back pain

Table 1
Overview of the two subgroups (participants with and without pain/pain-related disability).

	A	B
	Number of participants	Number of participants Mean value ± SD Range
CPI (*N* = 62)	#16 (26.8%)	#46 (74.2%) 39.49 ± 20.01 6.66–96.66
DISS (*N* = 64)	#24 (37.5%)	#40 (62.5%) 28.75 ± 19.06 3.33–70.00
$BPI_{Severity}$ (*N* = 62)	#28 (45.2%)	#34 (54.8%) 2.13 ± 1.73 0.25–7.00
$BPI_{Interfere}$ (*N* = 64)	#30 (46.9%)	#34 (53.1%) 2.22 ± 1.69 0.14–6.42

Based on the pain groupings, all participants were assigned to subgroup A if they indicated no pain and/or disability (score = 0), or to subgroup B if they indicated pain and/or disability (score > 0). The numbers of the participants belonging to the different subgroups are marked with "#" (percentage of total in brackets). For subgroup B, mean values (± SD) and the ranges regarding the intensity of pain and disability are also provided.

($N = 48$, 75%), with an average low to medium pain intensity ($CPI = 39.49 \pm 20.01$; $BPI_{Severity} = 2.13 \pm 1.73$) and related disability ($DISS = 28.75 \pm 19.06$; $BPI_{Interfere} = 2.22 \pm 1.69$). Moreover, the findings indicated a large variability within all four pain groupings (Table 1).

3.3. Sitting position classification and validation

Since most of the participants preferred to work with a fixed backrest, the positions "upright" (P_1) and "reclined" (P_2) were considered as one and the same position. The random forest classifier demonstrated an overall classification accuracy of 90% (Table 2) ranging from 70% up to 100% for the different participants.

3.4. Participant sitting behaviour

Participants worked on average 6.2 ± 1.5 h (range: 2.8–8.7 h), which resulted in 397 h of data collection. *SitBePar* captured 74% of the entire variance within the data and was therefore chosen to be the overall representative sitting behaviour parameter. The corresponding component loadings were 0.937 ($\hat{N}_{move}$), 0.629 ($\hat{N}_{pos}$), −0.931 ($\hat{t}_{stable}$), 0.902 ($P_{transient}$), comprised almost equally of all four sitting behaviour parameters except $\hat{N}_{pos}$, which was weighted slightly lower.

The *p*-values and Cohen's effect size of the two-tailed independent *t*-tests for *SitBePar* and the four grouping variables indicated that the relationship between sitting behaviour and chronic pain grouping variables (*CPI*: $p = 0.052$, $d = 0.579$; *DISS*: $p = 0.076$, $d = 0.471$) was higher than the relationship between *SitBePar* and acute pain conditions ($BPI_{Severity}$: $p = 0.625$, $d = 0.120$; $BPI_{Interfere}$: $p = 0.253$, $d = 0.291$).

Participants experiencing chronic LBP showed a lower overall percentage of transient periods (25.69 ± 11.69%) compared to pain-free participants (35.23 ± 14.55%) indicating a moderate effect ($p = 0.011$, d = 0.723). Similarly, a moderate effect ($p = 0.036$, $d = 0.544$) was observed between participants who felt disabled due to chronic LBP (*DISS*) (25.64 ± 12.28%) and corresponding non-disabled counterparts (32.75 ± 13.81%) (Figs. 2 and 3; Appendix: Table A1).

A closer analysis of the mean values indicated that participants with chronic pain and/or functional disability demonstrated less transient periods ($P_{transient}$) and less movements per hour (N_{move}), slightly fewer position changes per hour ($\hat{N}_{pos}$), and longer time periods of stable sitting ($\hat{t}_{stable}$) compared with corresponding counterparts (Figs. 2 and 3).

Mean values of almost all four sitting behaviour parameters for the four pain groupings indicated that participants with pain and pain related disability demonstrated a rather static sitting behaviour compared to their pain-free counterparts (Appendix: Table A1).

4. Discussion

This study aimed to analyse the relationships between sitting behaviour and LBP by investigating the sitting habits of call-centre workers whose assignments were undertaken in an almost continuous sitting position. We found a small association between general sitting behaviour and participants reporting chronic LBP and/or pain related functional disability. These observations over extended periods were consistent with reported sitting activity over short periods (1hr), where subjects also exhibited more frequent postural shifts than chronic LBP workers (Akkarakittichoke and Janwantanakul, 2017). The lack of a stronger relationship between LBP and sitting behaviour was most likely due to the highly multifactorial causality of LBP, including socio-psychological and physiological factors (Hoy et al., 2010). Another reason could be the complex and largely individual sitting habits, which are known to vary considerably among office workers (Goossens et al., 2012; Zemp et al., 2016a), thereby producing inhomogeneity in sitting behaviour.

Since almost all analysed sitting behaviour parameters for all pain groupings showed more dynamic activity in pain free participants, this study indicates a possible trend ($0.011 < p < 0.453$) towards a more static sitting behaviour among the majority of participants perceiving pain and/or suffering from pain related disability. These results are in line with several studies showing that participants with LBP or lumbar discomfort exhibit a more static sitting behaviour by demonstrating less micro-movements and longer periods of uninterrupted sitting (Zemp et al., 2016a; O'Keeffe et al., 2013; O'Sullivan et al., 2012b; Vergara and

Table 2
Leave-one-out cross-validation confusion matrix.

		Classified sitting position						Accuracy
		P_1/P_2	P_3	P_4	P_5	P_6	P_7	
Actual Sitting Position	P_1/P_2	**98.0%**	0.3%	0.3%	0.6%	0.3%	0.6%	**98.0%**
	P_3	6.9%	**91.1%**	1.0%	0.0%	0.0%	1.0%	**91.1%**
	P_4	14.7%	1.5%	**78.7%**	0.0%	0.0%	5.1%	**78.7%**
	P_5	15.8%	2.5%	0.0%	**76.7%**	5.0%	0.0%	**76.7%**
	P_6	0.0%	0.0%	0.5%	2.4%	**97.1%**	0.0%	**97.1%**
	P_7	0.5%	0.0%	1.0%	0.0%	0.5%	**98.1%**	**98.1%**
Precision		**87.7%**	**93.9%**	**95.5%**	**92.9%**	**96.2%**	**95.3%**	

Confusion matrix of the random forest classification algorithm with the actual sitting position shown in rows and the classified sitting positions in columns. The correctly classified cases (diagonal elements) are marked in bold. The sitting positions analysed were: upright and reclined together (P_1/P_2), forward inclined (P_3), laterally tilted right/left (P_4/P_5), crossed legs right over left/left over right (P_6/P_7).

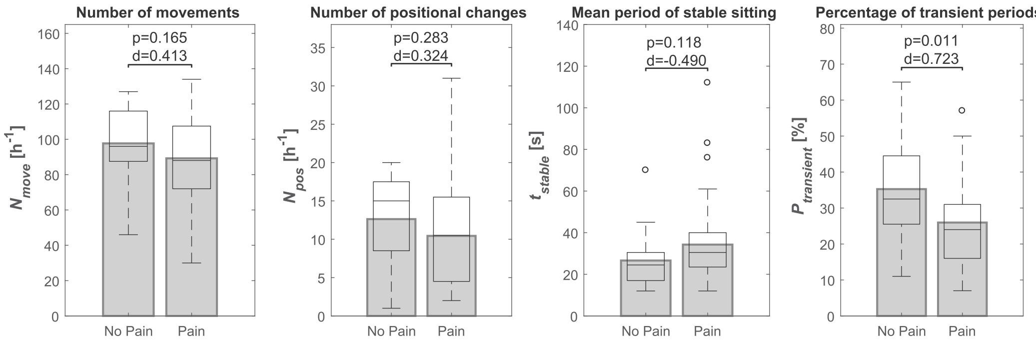

Fig. 2. Bar and box plots of the four different sitting behaviour parameters for the grouping variable CPI (chronic pain intensity) with the corresponding *t*-test's p-values and Cohen's effect sizes (d).

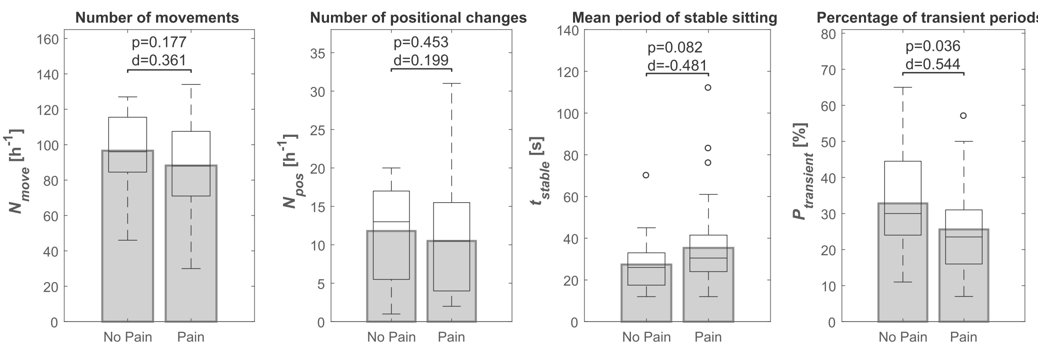

Fig. 3. Bar and box plots of the four different sitting behaviour parameters for the grouping variable DISS (chronic pain disability) with the corresponding *t*-test's p-values and Cohen's effect sizes (d).

Page, 2002; Womersley and May, 2006). A reasonable explanation for this observation could be the so-called “fear-avoidance behaviour” (Vlaeyen and Linton, 2000) meaning that, for instance, regular movements or positional alternation are reduced or avoided due to fear of experiencing pain (Vlaeyen et al., 2016).

In this study, a greater association between sitting behaviour and LBP was found for participants in the chronic LBP and/or related disability grouping than for those with acute pain/disability. It is therefore plausible that participants with chronic pain have a higher level of awareness to pain-free sitting positions and pain provoking movements compared to individuals affected by acute pain. Such an habitual awareness could result in fewer transitions between sitting positions as well as a reduction in small movements, indicating a type of avoidance learning based on their pain history (Krypotos, 2015). A similar phenomenon was reported by Panhale et al. (2016) who found a strong correlation between fear-avoidance belief and activity limitation in patients with chronic LBP; hence reflecting an underestimated impact of fear avoidance beliefs on the patient‘s behaviour.

Overall, transient periods were lower in participants with chronic LBP than pain free participants, indicating reduced movement throughout their working day. Since less frequent postural shifts have previously been observed among subjects with chronic LBP compared to healthy participants (Akkarakittichoke and Janwantanakul, 2017), it is likely that dominant drivers of sitting behaviour may exist that are related to chronic LBP. Although these results do not allow any conclusions nor definite statements to be drawn regarding a possible causal relationship or adaptational process among individuals with chronic LBP, a more static sitting behaviour is generally known to have physiological and biological consequences. Sustained pressure under the buttocks due to prolonged, uninterrupted sitting could be reduced by varying posture (Søndergaard et al., 2010; Vergara and Page, 2002; Zemp et al., 2015, 2016c, 2019) by means of e.g. regular pelvis rotations (van Geffen et al., 2008). Moreover, since continuous compression on an intervertebral disc can result in reduced disc nutrition (Kingma et al., 2000; Pynt et al., 2001) frequent postural movements are also recommended through lordosis and kyphosis. In this manner, sufficient metabolic balance of various musculoskeletal structures can be supported, including a reduction of ischaemic effects due to prolonged static sitting (Reenalda et al., 2009; Todd et al., 2007).

O'Sullivan et al. (2013) defined dynamic sitting as “increased motion in sitting, which is facilitated by the use of specific chairs or equipment”. However, recent studies have shown that dynamic chair equipment is not sufficient to affect muscle activation, postures and core kinematics (Ellegast et al., 2012; O'Sullivan et al., 2013; Grooten et al., 2017; Kingma and van Dieën, 2009). Therefore, it can be concluded that dynamic sitting should be actively stimulated, which can then be supported by dynamic chair mechanisms, indicating the requirement for a redefinition of dynamic sitting (Pynt, 2015). Such a redefinition, however, would require valid information in terms of movement patterns and positional changes that reflect a normal physiological sitting behaviour, which has not yet been fully established.

In order to enhance a more dynamic sitting behaviour among office employees, technical devices supporting dynamic sitting have recently been discussed. Several studies (Haller et al., 2011; Goossens et al., 2012; Davis and Kotowski, 2014) have demonstrated devices capable of monitoring behaviour and providing feedback for avoiding discomfort and musculoskeletal disorders at an early stage, with the aim to change sitting patterns among office workers. However, Roossien et al. (2017) reported that tactile feedback integrated into an office chair was unable to change sitting behaviour, suggesting that such feedback is insufficient for reducing musculoskeletal discomfort of office workers on a sustained basis. Their study used feedback signals to improve sitting duration in an “optimal supported posture”, instead of facilitating regular small movements, for instance. Therefore, tactile input combined with visual features may potentially promote more beneficial sitting habits than either alone (Straker et al., 2013). The textile pressure mat "sensomative science" used in the presented study, includes a corresponding smart phone application providing visual feedback of the current pressure distribution while sitting. Given further development in the application, for instance by enabling regular tactile or visual feedback to the user (smart phone or watch) to initiate small movements, could have potential for more dynamic sitting behaviour in sedentary office workers.

4.1. Limitations and remarks

In the present study only one working shift per employee was analysed, which might not comprehensively reflect the complete patterns of sitting behaviour in each individual. Our study aimed to achieve a general impression of sitting behaviour characteristics among a sedentary population of office workers. Since call-centre work is predominantly repetitive and inactive in nature (Thorp et al., 2012; Toomingas et al., 2012; Straker et al., 2013), call-centre employees were chosen as the focus group of our study. Indeed, observations during the ongoing measurements indicated that 95% of the working shift was indeed seated, except for scheduled breaks of 15–30 min within a working day – data that is highly consistent with the observations of Toomingas et al. (2012). This regular schedule indicated that our participants' work was not only highly sedentary, but also largely equivalent among all workers, which reduced confounding effects. It is also important to consider that, contrary to ergonomic guidelines, office tables and chairs were not ergonomically adjusted to each individual since the company's structure required regular workplace rotations within the office. To ensure ecological validity, the researchers did not intervene with the provided chair/table placement or rotation schedule. Nevertheless, the experimental setup including chair instrumentation, providing study information as well as the presence of the investigators could have altered the working routine.

From the results of our study, it seems that levels of LBP in call centre employees are only partially linked to sitting behaviour itself, and that the multifactorial nature of LBP is therefore possibly more associated with sedentary lifestyle or other factors such as job tenure, daily working hours, general fitness, customer reaction, and psychological stress etc. When examining sitting behaviour and its relationship with LBP, future studies should therefore consider these confounding variables, as well as different levels of pain intensity on a more continual scale. Since our study mainly analysed participants exhibiting on average low to medium back pain as well as pain related disability, such a detailed classification was not included and should therefore be addressed in future studies. An alternative classification of individuals with non-specific LBP can define subgroups similar to those presented by O'Sullivan (2005), distinguishing between mechanically and non-mechanically triggered pain. In this way, different pain drivers can be considered when analysing the relationship between sitting behaviour and LBP.

Due to the highly sedentary working conditions, call-centre employees are at particular risk of developing musculoskeletal disorders. As a result, these population-related characteristics need to be carefully considered when generalising these findings to the majority of office workers.

5. Conclusion

With scientific discussion to date leading to unclear relationships between sedentary lifestyle, sitting behaviour, and low back pain, we have provided standardised (real-world) conditions to investigate whether sitting behaviour and LBP are inherently linked. Our results show a possible trend towards more static sitting behaviour among call-centre workers with chronic LBP pain and pain related disability. A greater association was found between sitting behaviour and chronic LBP than for acute pain/disability, which was a possible result of the fact that participants with chronic pain have a higher level of awareness to pain-free sitting positions and pain provoking movements compared to individuals affected by acute pain.

Appendix

Table A1
Descriptive statistics of the different parameter of sitting behaviour (SitBePar, $\hat{N}_{move}$, $\hat{N}_{pos}$, $\hat{t}_{stable}$, $P_{transient}$) of the four pain groupings (CPI, DISS, $BPI_{Severity}$, $BPI_{Interfere}$).

	Parameter	Subgroups	Mean	SD	Min	Max
CPI	***SitBePar***	A: $CPI = 0$	0.40	0.92	−1.90	1.73
		B: $CPI > 0$	−0.15	0.98	−2.99	1.91
	$\hat{N}_{move}$ [h^{-1}]	A: $CPI = 0$	97.68	22.14	46.19	127.39
		B: $CPI > 0$	88.28	23.36	29.91	127.25
	$\hat{N}_{pos}$ [h^{-1}]	A: $CPI = 0$	12.58	6.12	1.10	20.07
		B: $CPI > 0$	10.47	6.87	1.51	30.63
	$\hat{t}_{stable}$ [s]	A: $CPI = 0$	26.59	14.27	11.77	69.68
		B: $CPI > 0$	34.75	18.76	12.19	112.44
	$P_{transient}$ [%]	A: $CPI = 0$	35.23	14.55	10.60	65.30
		B: $CPI > 0$	25.69	11.69	6.59	56.90
DISS	***SitBePar***	A: $DISS = 0$	0.28	0.85	−1.90	1.73
		B: $DISS > 0$	−0.17	1.05	−2.99	1.91
	$\hat{N}_{move}$ [h^{-1}]	A: $DISS = 0$	96.47	20.53	46.19	127.39
		B: $DISS > 0$	88.23	24.88	29.91	134.49
	$\hat{N}_{pos}$ [h^{-1}]	A: $DISS = 0$	11.76	5.93	1.10	20.07
		B: $DISS > 0$	10.46	7.08	1.51	30.63
	$\hat{t}_{stable}$ [s]	A: $DISS = 0$	27.38	12.54	11.77	69.68
		B: $DISS > 0$	35.38	19.92	12.19	112.44
	$P_{transient}$ [%]	A: $DISS = 0$	32.75	13.81	10.60	65.30
		B: $DISS > 0$	25.64	12.28	6.59	56.90

(continued on next page)

Table A1 (*continued*)

	Parameter	Subgroups	Mean	SD	Min	Max
$BPI_{Severity}$	*SitBePar*	A: $BPI_{Severity} = 0$	0.03	1.03	−2.99	1.73
		B: $BPI_{Severity} > 0$	−0.09	0.97	−2.12	1.91
	$\hat{N}_{move}$ $[h^{-1}]$	A: $BPI_{Severity} = 0$	90.66	23.88	29.91	127.39
		B: $BPI_{Severity} > 0$	90.76	23.81	39.03	134.49
	$\hat{N}_{pos}$ $[h^{-1}]$	A: $BPI_{Severity} = 0$	11.35	5.78	1.10	20.07
		B: $BPI_{Severity} > 0$	9.77	6.44	1.51	23.88
	$\hat{t}_{stable}$ [s]	A: $BPI_{Severity} = 0$	32.53	20.26	11.77	112.44
		B: $BPI_{Severity} > 0$	32.99	16.18	12.19	82.88
	$P_{transient}$ [%]	A: $BPI_{Severity} = 0$	29.56	13.82	6.59	65.30
		B: $BPI_{Severity} > 0$	26.64	12.73	10.15	56.90
$BPI_{Interfere}$	*SitBePar*	A: $BPI_{Interfere} = 0$	0.15	1.07	−2.99	1.91
		B: $BPI_{Interfere} > 0$	−0.14	0.92	−2.12	1.53
	$\hat{N}_{move}$ $[h^{-1}]$	A: $BPI_{Interfere} = 0$	93.33	24.02	29.91	127.39
		B: $BPI_{Interfere} > 0$	89.55	23.28	39.03	134.49
	$\hat{N}_{pos}$ $[h^{-1}]$	A: $BPI_{Interfere} = 0$	12.57	6.23	3.18	23.88
		B: $BPI_{Interfere} > 0$	9.51	6.77	1.10	31.63
	$\hat{t}_{stable}$ [s]	A: $BPI_{Interfere} = 0$	31.13	19.79	11.77	112.44
		B: $BPI_{Interfere} > 0$	33.48	16.16	13.39	82.88
	$P_{transient}$ [%]	A: $BPI_{Interfere} = 0$	30.55	13.89	6.59	65.30
		B: $BPI_{Interfere} > 0$	26.32	12.48	10.15	49.99

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