



UNICA

UNIVERSITÀ
DEGLI STUDI
DI CAGLIARI



Università di Cagliari

UNICA IRIS Institutional Research Information System

This is the Author's *accepted* manuscript version of the following contribution:

Arippa F, Leban B, Fadda P, Fancello G, Pau M., Trunk sway changes in professional bus drivers during actual shifts on long-distance routes. *Ergonomics*. 2022;65(5):762-774.

This is an Accepted Manuscript of an article published by Taylor & Francis in Ergonomics on 21 Oct 2021, available at:

<https://doi.org/10.1080/00140139.2021.1991002>

This full text was downloaded from UNICA IRIS <https://iris.unica.it/>

Trunk sway changes in professional bus drivers during actual shifts on long-distance routes

Federico Arippa^a, Bruno Leban^a, Paolo Fadda^{b,c}, Gianfranco Fancello^{b,c} and Massimiliano Pau^a

*^aDepartment of Mechanical, Chemical and Materials Engineering
University of Cagliari, Italy*

^bDepartment of Civil Engineering, Environment and Architecture, University of Cagliari, Italy

^cCENTRALABS Sardinian Center of Competence for Transportation, Cagliari, Italy

Corresponding author: Federico Arippa, Department of Mechanical, Chemical and Materials Engineering,
University of Cagliari, Piazza d'Armi, 09123 Cagliari, Italy

E-mail: arrippaf@gmail.com

ORCID: 0000-0002-4100-9189

Trunk sway changes in professional bus drivers during actual shifts on long-distance routes

Abstract

Although professional bus drivers are required to perform their task while adopting a prolonged constrained sitting posture, existence of possible effects in terms of postural strategies has been scarcely investigated under actual working conditions. This study aimed to characterize modifications of trunk sway in 14 professional bus drivers during regular shifts performed on non-urban routes using a pressure-sensitive mat placed on the seat. Center-of-pressure (COP) time series were extracted from body-seat pressure data to calculate sway parameters (i.e. sway area, COP path length, COP displacements and velocities). Results show generalized increase in trunk sway as driving progresses, which becomes statistically significant after approximately 70–100 minutes of continuous driving. This may indicate the adoption of specific strategies to cope with discomfort onset or a fatigue-induced alteration of postural features. Trunk sway monitoring of bus drivers may be useful in detecting postural behaviors potentially associated with deteriorating performance and discomfort onset.

Keywords: Sitting posture, Trunk postural sway, Prolonged driving, Bus drivers

Practitioner Summary

Professional bus drivers operate in sitting position for prolonged time. Such constrained posture may induce discomfort and fatigue. We investigated trunk sway during actual shifts using pressure-sensitive mats. Significant increase of sway was detected after 70min of continuous driving. Body-seat pressure data could be used as discomfort and fatigue markers.

1. Introduction

Professional bus drivers are required to efficiently and safely perform their task continuously up to 10 hours/day (Federal Motor Carrier Safety Administration, USA) and respect tight schedules while maintaining a fixed sitting position. In Europe, non-urban bus drivers operate both on long distances and for a prolonged time (i.e., 6 to 9 hours per day) having little or no control over their working environment (Tse et al., 2006) in terms of cockpit ergonomics, passengers' behavior (European Agency for Safety and Health at Work, 2011; Teixeira & Fischer, 2008) and traffic conditions (Querido et al., 2012). In particular, the first aspect may lead to a sort of "ergonomic mismatch" (i.e., disparity between drivers' anthropometric measures and the physical limits of the working environment) which has been identified as a co-factor in the onset of work-related musculoskeletal disorders (Yasobant et al., 2015).

It is not surprising to note that professional driving has been identified as one of the more stressful occupations (Hlotova et al., 2014; Bergomi et al., 2017). In addition, bus drivers may experience depression, anxiety and post-traumatic stress disorder due to negative passenger interaction (Evans, 1994; Ahlstrom et al., 2018). Driving is physically challenging, especially because drivers are forced to adopt prolonged non-neutral sitting postures (Beach et al., 2005; Lee et al., 2019), requiring constant activity of muscles involved in neck support, trunk stabilization and upper and lower limb movement (Joseph et al., 2020). The adoption of such a posture originates from the task requirement, which involves continuous control over the steering wheel and pedals while paying constant attention to the road environment (Van Veen & Vink, 2016). Moreover, body support action is mostly entrusted to the upper part of the body (in particular buttock and mid/low back regions) the lower limbs being mainly engaged in control

of both throttle and brake pedals. In the long term, such conditions expose drivers to fatigue and possibly pain (Andreoni et al., 2002; Lee & Gak, 2014; Joseph et al., 2020).

Constrained posture represents an important negative factor influencing discomfort (Andreoni et al., 2002; Waongenngarm et al., 2018) as the sustained submaximal contractions of back and trunk muscles maintained for long periods has been identified as a co-factor in the onset of discomfort and neuromuscular fatigue (El Falou et al., 2003; Baucher & Leborgne, 2006; Waongenngarm et al., 2015; Mörl & Bradl, 2013). In particular, muscle fatigue while driving (studied by examining changes in muscular tension in shoulder and neck muscles, Sheridan et al., 1991; Wikström, 1993; Balasubramanian & Adalarasu, 2007; Hirao et al., 2007) acutely impairs driver alertness and disrupts cognitive performance, leading to an overall decrease in transportation safety (Leinonen et al., 2005; Ting et al., 2008).

In such a context, there is the need for methods to assess drivers' workload, inattention and fatigue by adopting multi-method approaches able to identify relevant factors for estimating potential risky conditions (Lohani et al., 2019). Such approaches may allow indirect measurements of discomfort and/or fatigue to be made remotely, in a way less invasive than subjective discomfort ratings (Sammonds et al., 2017). To this purpose, several authors recently focused their research on prolonged sitting and its relationship with discomfort states using a variety of tools such as video analysis (Womersley & May, 2006; Kar & Hedge, 2021), accelerometers (Ryan et al., 2011; Jia & Nussbaum, 2018), optoelectronic systems (Dunk & Callaghan, 2005; Kwon et al., 2018; Cardoso et al., 2018), force sensors (Yamada et al., 2009; Zemp et al., 2016b; Wang et al., 2019) and pressure distribution sensors (Kyung & Nussbaum, 2013; Waongenngarm et al., 2020). Among them, pressure-sensitive mats represent a very

appealing solution owing to their easiness of setup and use (Bontrup et al., 2019) and their limited influence on the execution of the task (Zemp et al., 2016a). Moreover, body–seat contact pressure may represent an effective tool in assessing discomfort onset as this variable has been shown to be associated with drivers' subjective perception (de Looze et al., 2003; Dunk & Callaghan, 2005; Kolich et al., 2004).

One possible way to characterize the effects of prolonged sitting posture based on body–seat contact pressure involves analysis of trunk sway through processing of the center-of-pressure (COP, namely the point of application of the resultant of forces exchanged by body and seat) time series, focusing attention only on trunk stability (Vette et al., 2009; Serra-Añó et al., 2015; Leban et al., 2017). Postural sway has been widely investigated in the case of upright standing, and its features have been found extremely useful in research and clinical contexts in characterizing the performance of the postural control system (Visser et al., 2008). Similar to what is observed for standing, trunk stability has been demonstrated to be influenced by sensorimotor impairments caused, for example, by neurologic conditions such as brain and spinal cord injuries (Genthon et al., 2007; Perlmutter et al., 2010; Milosevic et al., 2015) and musculoskeletal disorders such as low back pain (Radebold et al., 2001). Interestingly, it has recently been reported that during prolonged sitting posture, trunk sway tends to increase with time, and this suggests its possible use as a biomarker for discomfort (Jin et al., 2009; Cardoso et al., 2016) and fatigue (Hendershot et al., 2013; Van Dieen et al., 2012; Leban et al., 2017). Even though recent studies have assessed postural strategies of professional drivers using pressure-sensitive mats (under both simulated and actual working conditions) only few of them investigated the effects of prolonged driving

sessions on trunk stability by means of continuous evaluation of sway parameters during shift time.

On the basis of the above considerations, the aim of this study is to characterize trunk sway and its relationship with discomfort in a cohort of professional experienced bus drivers during actual long shifts carried out on non-urban routes. The hypothesis to test is whether trunk sway, assessed by means of COP-based measures, increases as the work shift progresses. This may indicate the occurrence of changes in postural strategies over time adopted to cope with discomfort onset and (possibly) fatigue associated with the working load.

2. Materials and Methods

2.1 Participants

Fourteen experienced professional male bus drivers currently employed at the largest public transport regional company of Sardinia (ARST S.p.A. Cagliari, Italy) were recruited for this study on a voluntary basis. The absence of women in the participants' group was justified by the low percentage (2%) of drivers of this sex employed in the company. At the time of the experimental trials, participants were free from any musculoskeletal disorder that may have prevented them from regular employment in the past 12 months according to the company medical records and self-report. All participants provided written informed consent after a detailed explanation of the purpose and experimental methodologies of this study, which was conducted in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki declaration and its later amendments. Their main demographic and anthropometric features are reported in Table 1.

Please insert Table 1 approximately here

2.2 Experimental procedure

Drivers were tested in the period October–November 2018 during actual 6- to 9-hour shifts which included service on regional routes as scheduled by the company. Trials were performed on a standard passenger bus (i4 model, Irizar, Italy) with an air-suspension seat mounted in the cockpit. All shifts started either in the early morning or afternoon. Thus, in most cases, part of the task was performed under dawn or twilight conditions. As drivers operate on different routes (even though quite homogenous in terms of travel time, traffic conditions and tortuosity) in order to limit the influence of possible confounding effects, each path was monitored the same number of times in both directions (i.e., inbound and outbound). Overall, data on 72.5 hours of service was acquired and processed.

Before beginning the shift, all participants were allowed to adjust the bus seat at their convenience in terms of distance from the steering wheel, seatback angle and seat height. They were then asked to drive while maintaining their usual working posture (Figure 2). As per company policy, drivers must rest after approximately 120 minutes of continuous driving, taking breaks of variable duration (but not exceeding 45 minutes in any case) at the bus terminal. Thus, each trial of 6-9 hours was composed by two or four 120-min bouts. They were also required to verbally provide information about the perceived discomfort at the beginning of the trial and every 60 minutes while driving, using the two-part survey proposed by Sammonds et al. (2017).

Please insert Figure 1 approximately here

Contact pressure data at the body–seat interface was continuously collected by means of a pressure-sensitive mat (Tekscan 5330E 471.4 × 471.4 mm active area, 1024 sensing elements arranged in a 32 × 32 matrix) previously employed in similar studies (Andreoni et al., 2002; Pau et al., 2016; Leban et al., 2018) at 10 Hz sampling frequency. In order to prevent the mat from sliding, it was attached to the seat by using the dedicated strap eyelets of the sensor. The sensor was also connected to a two-port hub (Tekscan Versatek) and then to a PC via USB connection as shown in Figure 1. Before each trial, the mat was calibrated following the manufacturer’s instructions

Please insert Figure 2 approximately here

2.3 Data processing

Task-induced trunk sway was assessed based on COP time series acquired by the Tekscan system. Raw data were exported as text files using the management software provided by the manufacturer (Tekscan Conformat Research v.7.20) and post-processed using a dedicated custom software developed under the Matlab® environment (MathWorks, Inc, Natick, MA, USA). Based on raw COP trajectory data (Figure 3), the following trunk sway parameters were calculated:

- COP sway path (SP, mm): i.e. the overall distance traveled by the COP;
- COP maximum displacements: difference between maximum and minimum values of the selected coordinate recorded during the trial (mm), in AP and ML directions;

- Sway area (SA, mm²): area of the 95% bivariate confidence ellipse which is expected to enclose approximately 95% of the points of the COP path (Figure 3);
- Ellipse's centroid (EC): coordinates in antero-posterior (AP) and medio-lateral (ML) directions (mm) of the geometrical center of the ellipse (Figure 3);
- EC velocity (overall and relative to AP and ML directions): calculated as the average of instantaneous values recorded during the trial (mm s⁻¹) (Figure 3). EC velocity is calculated as the ratio between the distance travelled by the EC and the considered time-window duration.

Although most studies on trunk sway are based on the study of COP trajectory and velocity, we chose also to track the sway area centroid coordinates (EC) during the trial, because this parameter provides additional information on frequency of postural changes over time. EC may in fact be considered as the reference point around which the COP oscillates within a certain time window. Accordingly, analysis of EC velocity provides an idea of the frequency of postural variations/movements performed on the seat-pan over the shift time.

All sway parameters were calculated over 2.5-second windows and finally referred to the 15-minute blocks as follows:

- The Sway path length across a 15-min block, was obtained by summing the path lengths calculated for each 2.5 seconds periods:
- The Sway Area across a 15-min block was calculated as the sum of the sway areas calculated across each 2.5 seconds time period;
- COP displacements values were expressed as the maximum displacements of the COP across the 15-minute block;

- EC coordinates were the mean coordinates of the ellipse's centroid calculated across the 15-minute block;
- EC velocity was mean velocity of the EC across the 15-minutes block, calculated as the average velocity of all the 2.5-seconds windows.

The 2.5-second windows were chosen by means of pilot test data while the choice to average all parameters over 15-minute blocks was made following the protocol of previous similar research (Fenety et al., 2000, Cardoso et al., 2017). Data related to the first 5 minutes of each trial, as well as those of the first 5 minutes after any scheduled break, were discarded to remove any possible artifacts originated during the sitting- and seat-adjustment phases. During this time, drivers are still stabilizing their position on the seat, and driving conditions are not stationary.

Since after 120 minutes of continuous driving, as per company policy, drivers are obliged to take a scheduled break of 45 minutes (to rest and recover their physical comfort state) trials were segmented in chunks of maximum 120 minutes.

Please insert Figure 4 approximately here

2.4 Statistical analysis

The existence of changes in trunk sway parameters induced by the work shift was assessed by means of one-way analysis of variance for repeated measures (ANOVA-RM), setting time as the independent variable and the previously listed sway parameters as dependent variables. The significance level was set at $\alpha = 0.05$. Multiple comparison tests vs. baseline value of sway parameters (the value collected for the first 15-minute interval) were performed using the

Bonferroni method. Data were preliminarily checked for normality (using the Shapiro–Wilk test), homogeneity of variances (Levene’s test) and presence of outliers. Pearson product moment correlation analysis was also performed to assess the relationship between each sway parameter and shift time. The level of significance was set at $\alpha = 0.05$ also in this case. Qualitative trends across time of perceived discomfort ratings were evaluated.

3. Results

3.1. Sway parameters

The trends of sway parameters during the work shift are reported in Figure 4. The statistical analysis detected a significant effect of time on sway area [$F(7,159) = 2.86, p = 0.008$], EC velocity in the AP direction [$F(7,159) = 2.15, p = 0.043$] and COP maximum displacement in the ML direction [$F(7,159) = 3.46, p = 0.002$], while no effect was found for COP sway path [$F(7,159) = 2.08, p = 0.050$], EC overall velocity [$F(7,159) = 1.67, p = 0.122$] and ML direction [$F(7,159) = 1.42, p = 0.202$], COP maximum displacement in the AP direction [$F(7,159) = 1.84, p = 0.084$] and EC coordinates in both AP [$F(7,159) = 1.24, p = 0.287$] and ML [$F(7,159) = 0.90, p = 0.506$] directions.

Please insert table 2 approximately here

The results of the correlation analysis (reported in Table 2) show that all sway parameters, except for the EC coordinate in ML direction, were positively correlated with time. In particular, strong associations were observed for sway area, COP sway path, EC velocity and COP maximum displacements in the AP and ML directions (r in the range 0.81–0.93). EC coordinates were found

to be positively correlated with time only in the AP direction ($r = 0.81$). An example of changes in sway features with increasing time is shown in Figure 4.

Please insert Figure 5 approximately here

3.2. Perceived discomfort

The overall perceived discomfort rating trend over time is shown in Figure 5. Curve slopes for body regions and overall discomfort are reported in Table 3.

Please insert Figure 6 approximately here

Please insert Table 3 approximately here

4. Discussion

The purpose of the present study was to perform a long-term monitoring of trunk sway induced by the driving task in a cohort of professional bus drivers who perform their task on non-urban routes. In particular, we aimed to detect the onset of modifications of sitting postures and sway parameters associated with work shift progression, discomfort and/or fatigue to provide information on drivers' state. Generally speaking, our data reveal an increasing trend for both perceived discomfort and trunk sway parameters as driving time progresses, with significant changes in trunk movements occurring at different times from the beginning of the shift depending on the parameter considered. In particular, EC velocity in the AP direction and sway area were found to be significantly higher, with respect to the baseline values, after

approximately 100 minutes of continuous driving. Maximum COP displacements were found to increase with time: in particular, significant differences with respect to the baseline in the ML direction were reported after approximately 70 minutes from the beginning of the driving task. The EC coordinate moved forward significantly as the shift progressed.

Although to the authors' knowledge there is a lack of data on postural sway (assessed through COP-based measures) of bus drivers operating on long-distance routes, it is noteworthy that the results obtained here are partly consistent with those of Albert et al., (2014) who performed a similar analysis on 15 bus drivers by collecting COP data for 1 hour using pressure-sensitive mats. Although quantitative values of sway parameters were not explicitly reported, the authors described an increase in postural adjustments over the course of the trial, which was visible in terms of sway area enlargement. Our findings also appear consistent with those of previous studies performed on other kinds of workers forced to adopt prolonged sitting postures, such as office workers and quay crane operators (Fenety et al., 2000; Leban et al., 2017). Even in these cases, significant increases in trunk sway were observed during the shift.

Prolonged sitting has already been shown to be related to muscle fatigue due to sustained contraction of back muscles while sitting (Baucher & Lebrogne, 2006). Back muscle fatigue during sitting is induced in situations where an active posture is maintained, for example in vehicles where visual inspection of the environment, in front or on the sides, is required to avoid accidents (Santos et al., 2009), or when prolonged slumped sitting is maintained, and may compromise the stability of the spine (Waongenngarm et al., 2016). Given that, it can be hypothesized that, similar to what occurs in the case of upright stance, trunk muscle fatigue is able to originate delays in

neuromuscular protective reflexes and coordination (O'Sullivan et al., 2006) thus causing a loss in smoothness of movements (Cortes et al., 2014).

In this context, it is noteworthy that several laboratory studies (Hendershot et al., 2013; Van Dieen et al., 2012) have reported increases in trunk sway velocity in the AP direction following acute fatiguing protocols. Moreover, a recent study on quay crane operators operating in a simulated environment found that sway area and COP velocity significantly increase after 2 and 1 hour from the beginning of the work shift, respectively (Leban et al., 2017). Although a direct relationship between objective measurements of fatigue and trunk sway has not been established so far, such findings, which are consistent with those observed in the present study, suggest that the increase in COP sway path and sway area as the shift progresses might be related to cumulative muscular fatigue associated with the combination of driving task and prolonged constrained posture.

Interestingly, we also observed an increase in EC velocity over time. As defined herein, EC velocity considers only the velocity of rigid shifts, not including instantaneous fluctuations of COP due, for instance, to the roughness of the road pavement. This fact suggests that the velocity – or frequency – of postural adjustments increases over time, thus indicating a higher frequency in changes of “reference” posture changes within the trial. Such changes may be related either to the task demands (i.e. turning, pedals controls, ...) or to negative perception of the physical state (e.g., discomfort, pain relief, ...).

The observed increase in sway parameters can be explained by considering two factors: 1) it may represent a specific strategy adopted to cope with discomfort onset and 2) the onset of neuromuscular fatigue cumulated as the shift progresses may significantly impair drivers'

postural abilities. As regards the former aspect, Le et al. (2014) suggest that individuals forced to spend a long time in a sitting posture continuously attempt to alleviate discomfort through slight movements. This interpretation is in line with the theory of Hermann and Bubb (2007), who hypothesized that drivers move automatically to relieve pressure on more compressed body parts causing them discomfort. As the duration of sitting increases, drivers reach the discomfort threshold more quickly as time progresses and thus fidget more frequently (Sammonds et al., 2017). As regards the second point, it is known that in an orthostatic position, body sway reflects overall performance of postural control system, representing the amount of muscular activity necessary to achieve the required stability (Cameron & Huisinga, 2013; Serra-Añó et al., 2015). Thus, an increase in sway is likely to indicate that the amount of muscular activity necessary to achieve stability also increases with time due to a deterioration in postural control system performance. In particular, Serra-Añó et al. (2015) reported that COP velocity reflects the neuromuscular activity necessary to maintain balance, so alterations in COP velocity may be explained as a consequence of fatigue onset. Previous researchers (Vuillerme et al., 2007) have found that an increase can be seen in movement amplitude in a trunk-fatigued condition compared to a non-fatigued condition. Despite cited results referring to conditions different from those considered in the present study (i.e. standing posture), some researchers consider it reasonable that, similar to that case, localized trunk fatigue can induce a proprioceptive deficit that affects neuromuscular reflexes and coordination also in a seated posture (O'Sullivan et al., 2006). In this regard, Vette et al. (2009) compared upright and sitting sway patterns, finding a correlation in sway velocity between the two tasks; nevertheless, the authors suggest that great caution needs to be exercised in comparing sitting and standing tasks, as there are important

differences in the motor-control schemes involved. A plausible explanation for sway velocity increase over time may be that the stabilizing muscle activity is altered by the onset of fatigue (Cortes et al., 2014), thus resulting in impaired effectiveness of overall postural control.

Our results regarding COP maximum displacements, although in contrast with Sammonds et al. (2017) who observed no increase in seat fidgeting magnitude with duration of simulated driving, appear to be quite consistent with those of Leban et al. (2017) and Cardoso et al. (2017). These authors identified an increase in COP displacements over time in the AP and ML directions. The discrepancy between our results and those reported by Sammonds et al., (2017) is probably due to the design of the method employed by those authors, where movement magnitude was defined by the type of movement (i.e. only leg, only torso or whole body movements) and assessed by means of video analysis: the authors acknowledged the limitations of such an approach, stating that if a method assessing magnitude of movement in terms of distance and duration had been implemented, there would have been a chance that very different results may be observed. It is noteworthy that some movements (both in the AP and ML directions) may reflect the actual driving task requirements (i.e. turning the steering wheel during turns, checking mirrors, operating controls to allow passenger access, etc.) and that a non-homogeneous distribution of turns, stops and straights (for example, more frequent at the beginning rather than at the end of the trial and vice versa) may influence drivers' movements. In this regard, the particular setup employed in the present study mitigates this phenomenon, as each route was traveled the same number of times in both directions: in this way, an increase or decrease in parameter values is more likely to reflect the operator's behavior and not the effect of the

particular route traveled. It thus appears reasonable to the authors to affirm that the excess of movement noticed over time may be mostly caused by onset of fatigue and/or discomfort.

The existence of significant displacements of the EC in the AP direction as the shift progresses detected in our sample is in contrast to that observed by Albert et al. (2014); nevertheless, the same behavior has been reported by Jin et al. (2009), who saw that after driving a long time, drivers tend to “slip forward” on the seat, thus shifting the COP forward on the seat pan. Hendriks et al. (2006) explained this phenomenon by suggesting that drivers progressively “slouch” (slide/slip forward) in their seats over time in an attempt to reduce their driving fatigue by looking for extra support from the seatback (Hendriks et al., 2006). Differences in the AP shift with respect to Albert et al. (2014) may be due to differences in the experimental setup. In fact, Albert et al.’s study was conducted during rush hours in the Canadian winter, and thus road/traffic conditions may have had a significant impact. The trial duration is also different in the two studies: in particular, Albert et al.’s (2014) trials were performed over one-hour windows, while we monitored longer periods, with at least 2 hours of continuous driving. Contrary to Jin et al. (2009), who observed a shift of the body toward the left side of the seat pan as time progressed, we found no significant trend in the ML direction. It can be hypothesized that this discrepancy is owing to the fact that the present study was conducted on real routes while the latter was in a laboratory setup; furthermore, subjects participating in Jin et al.’s (2009) study were not professional drivers. Other possible factors that introduce discrepancies with the previously mentioned studies include the presence of vibrations from road/vehicle (which may improve peripheral and leg blood flow, Lythgo et al., 2009; Games et al., 2015) and the number of left/right turns, which may indirectly help to periodically relieve contact pressure in the buttock

region, thus influencing the driver's need to bend laterally on the seat. Additionally, the particular seat ergonomics of professional cockpits may give sufficient external support both to the left and right legs, whereas less support is given by the foot implicated in pedal control.

Another important aspect must be considered, namely the high cognitive load required by bus drivers to guarantee transport safety. Fatigued drivers have been demonstrated to face greater attention demands compared to non-fatigued ones (Liu & Wu, 2009), and this can be considered a cofactor influencing the effectiveness of postural control. In this sense, previous studies have reported significant increases in sway when a cognitive task was added while maintaining a sitting posture (Igarashi et al., 2016). Finally, it is interesting to highlight that the perceived discomfort levels referring to the body regions are related with time. Upper back discomfort grows over time, as well as discomfort of the sitting bones region; passing from the lower back to the edge-of-seat contact, we can see that curve slopes rise. This fact may be due to the particular slouched posture assumed by drivers after some time spent driving: slipping forward may cause the operator to no longer have contact of the low back area with the seat; in this way, regions in direct contact with the seat and subjected to high contact pressures appear to be more sensitive to increases in discomfort over time compared to those areas subjected to lower or no pressure.

Some limitations of the study must be acknowledged. Firstly, we did not include in the analysis some anthropometric features of the participants which might influence trunk sway, such as height and body mass. Secondly, we did not collect any data on pressure distribution for the seatback, and this could have provided additional information useful to better characterize the adopted postural strategy. Thirdly, given the nature of the study, we were unable to set test

start and end times, and therefore some trials were performed under different light and — probably — traffic conditions. As this was a real-world study, drivers were also highly engaged in their work, paying great attention to the road, and thus only three values per-subject on perceived discomfort were collected in such a way as to minimize drivers' distractions. For this reason, we evaluated only the discomfort trend over time and did not study in depth its relationship with trunk sway variables. For the same reason, our data are not completely homogeneous regarding work-shifts duration (which was either 6 or 9 hours), and thus only the net effect associated with each 120-minute bout of continuous driving task on postural behavior was considered. Moreover, some quantitative data should be collected on driver fatigue and cognitive workload to establish if a direct link with sway parameters exists. In particular, it would be interesting to evaluate how different types of fatigue change over time (fatigue caused by discomfort, musculoskeletal fatigue due to prolonged trunk muscle exertion and cognitive fatigue) to assess if, and in which order, postural sway may be influenced. Finally, we were unable to collect video recordings of drivers during the trials. The availability of such data would have been useful in better interpreting the experimental data in terms of postural adjustments.

In summary, the results of the present study reveal an increase in sway amplitude and velocities, thus suggesting the adoption by drivers of peculiar postural strategies to cope with discomfort onset and/or fatigue-induced deterioration of postural control abilities. Although the exact association with discomfort, fatigue and risk of potential increased musculoskeletal disorders remains unclear, sway parameters appear to be related to the former, as they show a similar trend over time. Such a non-intrusive technique allows assessment of trunk oscillation over time and may be incorporated in sensorized cockpits that enable the remote and continuous

monitoring of drivers' conditions during the shift. This may lead to work schedule modifications to prevent or alleviate discomfort and fatigue onset. Further studies on larger cohorts are necessary to fully investigate the relationship between trunk sway, discomfort and fatigue level along with postural performance deterioration. Finally, it would be interesting to see if results obtained herein are generalizable to driver categories other than bus drivers.

Acknowledgements

The authors wish to thank the ARST S.p.A. company and all drivers who participated in the study for their availability. In particular, the support provided by Francesca Sulis was greatly appreciated.

Conflict of interest

The authors report no conflicts of interest.

Funding

This research received no specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Data availability

The data associated with the paper are not publicly available but are available from the corresponding authors on reasonable request.

References

- Ahlström, C., Gink Lövgren, M., Nilsson, M., Dukic Willstrand, T., & Anund, A. (2019). The effect of an active steering system on city bus drivers' muscle activity. *International Journal of Occupational Safety and Ergonomics*, 25(3), 377–385. <https://doi.org/10.1080/10803548.2018.1445465>
- Albert, W. J., Everson, D., Rae, M., Callaghan, J. P., Croll, J., & Kuruganti, U. (2014). Biomechanical and ergonomic assessment of urban transit operators. *Work*, 47(1), 33–44. <https://doi.org/10.3233/WOR-131683>
- Andreoni, G., Santambrogio, G. C., Rabuffetti, M., & Pedotti, A. (2002). Method for the analysis of posture and interface pressure of car drivers. *Applied Ergonomics*, 33(6), 511–522. [https://doi.org/10.1016/S0003-6870\(02\)00069-8](https://doi.org/10.1016/S0003-6870(02)00069-8)
- Balasubramanian, V., & Adalarasu, K. (2007). EMG-based analysis of change in muscle activity during simulated driving. *Journal of Bodywork and Movement Therapies*, 11(2), 151–158. <https://doi.org/10.1016/j.jbmt.2006.12.005>
- Baucher, J., & Leborgne, P. (2006). Application d'une approche transversale de l'appareil locomoteur au confort siège. *Itbm-Rbm*, 27(3), 133–140. <https://doi.org/10.1016/j.rbmret.2006.05.002>
- Beach, T. A. C., Parkinson, R. J., Stothart, J. P., & Callaghan, J. P. (2005). Effects of prolonged sitting on the passive flexion stiffness of the in vivo lumbar spine. *Spine Journal*, 5(2), 145–154. <https://doi.org/10.1016/j.spinee.2004.07.036>
- Bergomi, M., Modenese, A., Ferretti, E., Ferrari, A., Licitra, G., Vivoli, R., ... Aggazzotti, G. (2017). Work-related stress and role of personality in a sample of Italian bus drivers. *Work*, 57(3), 433–440. <https://doi.org/10.3233/WOR-172581>
- Bontrup, C., Taylor, W. R., Fliesser, M., Visscher, R., Green, T., Wippert, P. M., & Zemp, R. (2019). Low back pain and its relationship with sitting behaviour among sedentary office workers. *Applied Ergonomics*, 81. <https://doi.org/10.1016/j.apergo.2019.102894>
- Cameron, M. H., & Huisinga, J. (2013). Objective and subjective measures reflect different aspects of balance in multiple sclerosis. *Journal of Rehabilitation Research and Development*, 50(10), 1401–1409. <https://doi.org/10.1682/JRRD.2013.02.0042>
- Cardoso, M., Fulton, F., McKinnon, C., Callaghan, J. P., Johnson, M. J., & Albert, W. J. (2019). Ergonomic evaluation of a new truck seat design: a field study. *International Journal of Occupational Safety and Ergonomics*, 25(3), 331–343. <https://doi.org/10.1080/10803548.2017.1348056>

- Cardoso, M., Girouard, M., McKinnon, C., Callaghan, J. P., & Albert, W. J. (2017). Quantifying the postural demands of patrol officers: a field study. *International Journal of Occupational Safety and Ergonomics*, 23(2), 185–197. <https://doi.org/10.1080/10803548.2016.1249729>
- Cardoso, M., McKinnon, C., Viggiani, D., Johnson, M. J., Callaghan, J. P., & Albert, W. J. (2018). Biomechanical investigation of prolonged driving in an ergonomically designed truck seat prototype. *Ergonomics*, 61(3), 367–380. <https://doi.org/10.1080/00140139.2017.1355070>
- Cortes, N., Onate, J., & Morrison, S. (2014). Differential effects of fatigue on movement variability. *Gait and Posture*, 39(3), 888–893. <https://doi.org/10.1016/j.gaitpost.2013.11.020>
- De Looze, M. P., Kuijt-Evers, L. F. M., & Van Dieën, J. (2003). Sitting comfort and discomfort and the relationships with objective measures. *Ergonomics*. <https://doi.org/10.1080/0014013031000121977>
- Dunk, N. M., & Callaghan, J. P. (2005). Gender-based differences in postural responses to seated exposures. *Clinical Biomechanics*, 20(10), 1101–1110. <https://doi.org/10.1016/j.clinbiomech.2005.07.004>
- El Falou, W., Duchêne, J., Grabisch, M., Hewson, D., Langeron, Y., & Lino, F. (2003). Evaluation of driver discomfort during long-duration car driving. *Applied Ergonomics*, 34(3), 249–255. [https://doi.org/10.1016/S0003-6870\(03\)00011-5](https://doi.org/10.1016/S0003-6870(03)00011-5)
- European Agency for Safety and Health at Work. (2011). OSH in figures: Occupational safety and health in the transport sector - an overview. doi:10.2802/2218
- Evans, L. (1994). Driver injury and fatality risk in two-car crashes versus mass ratio inferred using Newtonian mechanics. *Accident Analysis and Prevention*, 26(5), 609–616. [https://doi.org/10.1016/0001-4575\(94\)90022-1](https://doi.org/10.1016/0001-4575(94)90022-1)
- Fenety, P.A., Putnam, C., & Walker, J. M. (2000). In-chair movement: Validity, reliability and implications for measuring sitting discomfort. *Applied Ergonomics*, 31(4), 383–393. [https://doi.org/10.1016/S0003-6870\(00\)00003-X](https://doi.org/10.1016/S0003-6870(00)00003-X)
- Games, K. E., Sefton, J. E. M., & Wilson, A. E. (2015). Whole-body vibration and blood flow and muscle oxygenation: A meta-analysis. *Journal of Athletic Training*, 50(5), 542–549. <https://doi.org/10.4085/1062-6050-50.2.09>
- Genthon, N., Vuillerme, N., Monnet, J. P., Petit, C., & Rougier, P. (2007). Biomechanical assessment of the sitting posture maintenance in patients with stroke. *Clinical Biomechanics*, 22(9), 1024–1029. <https://doi.org/10.1016/j.clinbiomech.2007.07.011>

- Hendershot, B. D., Toosizadeh, N., Muslim, K., Madigan, M. L., & Nussbaum, M. A. (2013). Evidence for an exposure-response relationship between trunk flexion and impairments in trunk postural control. *Journal of Biomechanics*, *46*(14), 2554–2557. <https://doi.org/10.1016/j.jbiomech.2013.07.021>
- Hendriks, H. M., Spoor, C. W., De Jong, A. M., & Goossens, R. H. M. (2006). Stability of sitting postures: The influence of degrees of freedom. *Ergonomics*, *49*(15), 1611–1626. <https://doi.org/10.1080/00140130600899161>
- Hermann, S., & Bubb, H. (2007). Development of an objective measure to quantify automotive discomfort over time. In *IEEE International Symposium on Industrial Electronics* (pp. 2824–2830). <https://doi.org/10.1109/ISIE.2007.4375059>
- Hirao, A., Kato, K., Kitazaki, S., & Yamazaki, N. (2007). Evaluations of physical fatigue during long-term driving with a new driving posture. In *SAE Technical Papers*. <https://doi.org/10.4271/2007-01-0348>
- Hlotova, Y., Cats, O., & Meijer, S. (2014). Measuring bus drivers' occupational stress under changing working conditions. *Transportation Research Record*, *2415*, 13–20. <https://doi.org/10.3141/2415-02>
- Igarashi, G., Karashima, C., & Hoshiyama, M. (2016). Effect of Cognitive Load on Seating Posture in Children. *Occupational Therapy International*, *23*(1), 48–56. <https://doi.org/10.1002/oti.1405>
- Jia, B., & Nussbaum, M. A. (2018). Influences of continuous sitting and psychosocial stress on low back kinematics, kinetics, discomfort, and localized muscle fatigue during unsupported sitting activities. *Ergonomics*, *61*(12), 1671–1684. <https://doi.org/10.1080/00140139.2018.1497815>
- Jin, X., Cheng, B., Wang, B., & Shen, B. (2009). Assessment of driver's seating discomfort using interface pressure distribution. In *IEEE Intelligent Vehicles Symposium, Proceedings* (pp. 1419–1424). <https://doi.org/10.1109/IVS.2009.5164493>
- Joseph, L., Standen, M., Paungmali, A., Kuisma, R., Silitertpisan, P., & Pirunsan, U. (2020). Prevalence of musculoskeletal pain among professional drivers: A systematic review. *Journal of Occupational Health*. <https://doi.org/10.1002/1348-9585.12150>
- Kar, G., & Hedge, A. (2021). Effect of workstation configuration on musculoskeletal discomfort, productivity, postural risks, and perceived fatigue in a sit-stand-walk intervention for computer-based work. *Applied Ergonomics*, *90*. <https://doi.org/10.1016/j.apergo.2020.103211>

- Kolich, M., Seal, N., & Taboun, S. (2004). Automobile seat comfort prediction: Statistical model vs. artificial neural network. *Applied Ergonomics*, 35(3), 275–284. <https://doi.org/10.1016/j.apergo.2004.01.007>
- Kwon, Y., Kim, J. W., Heo, J. H., Jeon, H. M., Choi, E. B., & Eom, G. M. (2018). The effect of sitting posture on the loads at cervico-thoracic and lumbosacral joints. In *Technology and Health Care* (Vol. 26, pp. S409–S418). <https://doi.org/10.3233/THC-174717>
- Kyung, G., & Nussbaum, M. A. (2013). Age-related difference in perceptual responses and interface pressure requirements for driver seat design. *Ergonomics*, 56(12), 1795–1805. <https://doi.org/10.1080/00140139.2013.840391>
- Le, P., Rose, J., Knapik, G., & Marras, W. S. (2014). Objective classification of vehicle seat discomfort. *Ergonomics*, 57(4), 536–544. <https://doi.org/10.1080/00140139.2014.887787>
- Leban, B., Arippa, F., Fancello, G., Fadda, P., & Pau, M. (2019). Analysis of discomfort during a 4-hour shift in quay crane operators objectively assessed through in-chair movements. In *Advances in Intelligent Systems and Computing* (Vol. 823, pp. 90–100). https://doi.org/10.1007/978-3-319-96074-6_10
- Leban, B., Fancello, G., Fadda, P., & Pau, M. (2017). Changes in trunk sway of quay crane operators during work shift: A possible marker for fatigue? *Applied Ergonomics*, 65, 105–111. <https://doi.org/10.1016/j.apergo.2017.06.007>
- Lee, D. W., Hong, Y. C., Seo, H. Y., Cho, S. J., Nam, S. H., Park, C. J., & Lee, N. (2019). Poor Work-Life Balance May Lead to Impaired Cognitive Function in Bus Drivers. *Journal of Occupational and Environmental Medicine*, 61(10), e406–e412. <https://doi.org/10.1097/JOM.0000000000001675>
- Lee, J. H., & Gak, H. B. (2014). Effects of self stretching on pain and musculoskeletal symptom of bus drivers. *Journal of Physical Therapy Science*, 26(12), 1911–1914. <https://doi.org/10.1589/jpts.26.1911>
- Leinonen, V., Kankaanpää, M., Vanharanta, H., Airaksinen, O., & Hänninen, O. (2005). Back and neck extensor loading and back pain provocation in urban bus drivers with and without low back pain. *Pathophysiology*, 12(4), 249–255. <https://doi.org/10.1016/j.pathophys.2005.09.004>
- Liu, Y. C., & Wu, T. J. (2009). Fatigued driver's driving behavior and cognitive task performance: Effects of road environments and road environment changes. *Safety Science*, 47(8), 1083–1089. <https://doi.org/10.1016/j.ssci.2008.11.009>

- Lohani, M., Payne, B. R., & Strayer, D. L. (2019). A review of psychophysiological measures to assess cognitive states in real-world driving. *Frontiers in Human Neuroscience*. <https://doi.org/10.3389/fnhum.2019.00057>
- Lythgo, N., Eser, P., De Groot, P., & Galea, M. (2009). Whole-body vibration dosage alters leg blood flow. *Clinical Physiology and Functional Imaging*, 29(1), 53–59. <https://doi.org/10.1111/j.1475-097X.2008.00834.x>
- Milosevic, M., Masani, K., Kuipers, M. J., Rahouni, H., Verrier, M. C., McConville, K. M. V., & Popovic, M. R. (2015). Trunk control impairment is responsible for postural instability during quiet sitting in individuals with cervical spinal cord injury. *Clinical Biomechanics*, 30(5), 507–512. <https://doi.org/10.1016/j.clinbiomech.2015.03.002>
- Mörl, F., & Bradl, I. (2013). Lumbar posture and muscular activity while sitting during office work. *Journal of Electromyography and Kinesiology*, 23(2), 362–368. <https://doi.org/10.1016/j.jelekin.2012.10.002>
- O’Sullivan, P., Dankaerts, W., Burnett, A., Straker, L., Bargon, G., Moloney, N., ... Tsang, S. (2006). Lumbopelvic kinematics and trunk muscle activity during sitting on stable and unstable surfaces. *Journal of Orthopaedic and Sports Physical Therapy*, 36(1), 19–25. <https://doi.org/10.2519/jospt.2006.36.1.19>
- Pau, M., Leban, B., Fadda, P., Fancello, G., & Nussbaum, M. A. (2016). Effect of prolonged sitting on body-seat contact pressures among quay crane operators: A pilot study. *Work*, 55(3), 605–611. <https://doi.org/10.3233/WOR-162434>
- Perlmutter, S., Lin, F., & Makhsous, M. (2010). Quantitative analysis of static sitting posture in chronic stroke. *Gait and Posture*, 32(1), 53–56. <https://doi.org/10.1016/j.gaitpost.2010.03.005>
- Querido, A., Nogueira, T., Gama, R., & Orlando, J. (2012). Ergonomic work analysis of urban bus drivers in Rio de Janeiro city. In *Work* (Vol. 41, pp. 5956–5958). <https://doi.org/10.3233/WOR-2012-0993-5956>
- Radebold, A., Cholewicki, J., Polzhofer, G. K., & Greene, H. S. (2001). Impaired postural control of the lumbar spine is associated with delayed muscle response times in patients with chronic idiopathic low back pain. *Spine*, 26(7), 724–730. <https://doi.org/10.1097/00007632-200104010-00004>
- Ryan, C. G., Grant, P. M., Dall, P. M., & Granat, M. H. (2011). Sitting patterns at work: Objective measurement of adherence to current recommendations. *Ergonomics*, 54(6), 531–538. <https://doi.org/10.1080/00140139.2011.570458>

- Sammonds, G. M., Fray, M., & Mansfield, N. J. (2017). Effect of long term driving on driver discomfort and its relationship with seat fidgets and movements (SFM). *Applied Ergonomics*, *58*, 119–127. <https://doi.org/10.1016/j.apergo.2016.05.009>
- Santos, C.M.C., Oliveira, S.K.R., GonçAlves, J.S., Oliveira, L.P., Saldanha, M.C.W. (2009). Levantamento das demandas ergonomicas dos motoristas dos circulares de uma universidade federal: Um estudo de caso. *Encontro Nacional de Engenharia de Producao (ENEGEP)*.
- Serra-Añó, P., López-Bueno, L., García-Massó, X., Pellicer-Chenoll, M. T., & González, L. M. (2015). Postural control mechanisms in healthy adults in sitting and standing positions. *Perceptual and Motor Skills*, *121*(1), 119–134. <https://doi.org/10.2466/26.25.PMS.121c10x4>
- Sheridan, T. B., Meyer, J. E., Roy, S. H., Decker, K. S., Yanagishima, T., & Kishi, Y. (1991). Physiological and psychological evaluations of driver fatigue during long term driving. In *SAE Technical Papers*. <https://doi.org/10.4271/910116>
- Teixeira, M. L. P., & Fischer, F. M. (2008). Acidentes e doenças do trabalho notificadas, de motoristas profissionais do Estado de São Paulo. *Sao Paulo Em Perspectiva*, *22*(1), 66–78.
- Ting, P. H., Hwang, J. R., Doong, J. L., & Jeng, M. C. (2008). Driver fatigue and highway driving: A simulator study. *Physiology and Behavior*, *94*(3), 448–453. <https://doi.org/10.1016/j.physbeh.2008.02.015>
- Tse, J. L. M., Flin, R., & Mearns, K. (2006). Bus driver well-being review: 50 years of research. *Transportation Research Part F: Traffic Psychology and Behaviour*, *9*(2), 89–114. <https://doi.org/10.1016/j.trf.2005.10.002>
- Van Dieën, J. H., Luger, T., & Van Der Eb, J. (2012). Effects of fatigue on trunk stability in elite gymnasts. *European Journal of Applied Physiology*, *112*(4), 1307–1313. <https://doi.org/10.1007/s00421-011-2082-1>
- Van Veen, S., & Vink, P. (2016). Posture variation in a car within the restrictions of the driving task. *Work*, *54*(4), 887–894. <https://doi.org/10.3233/WOR-162359>
- Vette, A. H., Masani, K., Sin, V., & Popovic, M. R. (2010). Posturographic measures in healthy young adults during quiet sitting in comparison with quiet standing. *Medical Engineering and Physics*, *32*(1), 32–38. <https://doi.org/10.1016/j.medengphy.2009.10.005>
- Visser, J. E., Carpenter, M. G., van der Kooij, H., & Bloem, B. R. (2008). The clinical utility of posturography. *Clinical Neurophysiology*. <https://doi.org/10.1016/j.clinph.2008.07.220>

- Vuillerme, N., Anziani, B., & Rougier, P. (2007). Trunk extensor muscles fatigue affects undisturbed postural control in young healthy adults. *Clinical Biomechanics*, 22(5), 489–494. <https://doi.org/10.1016/j.clinbiomech.2007.01.007>
- Wang, X., Cardoso, M., Theodorakos, I., Beurier, G. (2019). A parametric investigation on seat/occupant contact forces and their relationship with initially perceived discomfort using a configurable seat. *Ergonomics*, 62(7), 891-902. doi:10.1080/00140139.2019.1600050
- Waongenngarm, P., Rajaratnam, B. S., & Janwantanakul, P. (2015). Perceived body discomfort and trunk muscle activity in three prolonged sitting postures. *Journal of Physical Therapy Science*, 27(7), 2183–2187. <https://doi.org/10.1589/jpts.27.2183>
- Waongenngarm, P., Rajaratnam, B. S., & Janwantanakul, P. (2016). Internal Oblique and Transversus Abdominis Muscle Fatigue Induced by Slumped Sitting Posture after 1 Hour of Sitting in Office Workers. *Safety and Health at Work*, 7(1), 49–54. <https://doi.org/10.1016/j.shaw.2015.08.001>
- Waongenngarm, P., van der Beek, A. J., Akkarakittichoke, N., & Janwantanakul, P. (2020). Perceived musculoskeletal discomfort and its association with postural shifts during 4-h prolonged sitting in office workers. *Applied Ergonomics*, 89. <https://doi.org/10.1016/j.apergo.2020.103225>
- Wikström, B. O. (1993). Effects from twisted postures and whole-body vibration during driving. *International Journal of Industrial Ergonomics*, 12(1–2), 61–75. [https://doi.org/10.1016/0169-8141\(93\)90038-F](https://doi.org/10.1016/0169-8141(93)90038-F)
- Womersley, L., & May, S. (2006). Sitting Posture of Subjects With Postural Backache. *Journal of Manipulative and Physiological Therapeutics*, 29(3), 213–218. <https://doi.org/10.1016/j.jmpt.2006.01.002>
- Yamada, M., Kamiya, K., Kudo, M., Nonaka, H., & Toyama, J. (2009). Soft authentication and behavior analysis using a chair with sensors attached: Hipprint authentication. *Pattern Analysis and Applications*, 12(3), 251–260. <https://doi.org/10.1007/s10044-008-0124-z>
- Yasobant, U., Ch, M.S., Reddy, E.M. Are Bus Drivers at an Increased Risk for Developing Musculoskeletal Disorders? An Ergonomic Risk Assessment Study. (2015). *Journal of Ergonomics*, S3, 1-5. doi:10.4172/2165-7556.S3-011.
- Zemp, R., Fliesser, M., Wippert, P. M., Taylor, W. R., & Lorenzetti, S. (2016). Occupational sitting behaviour and its relationship with back pain - A pilot study. *Applied Ergonomics*, 56, 84–91. <https://doi.org/10.1016/j.apergo.2016.03.007>
- Zemp, R., Tanadini, M., Plüss, S., Schnüriger, K., Singh, N. B., Taylor, W. R., & Lorenzetti, S. (2016). Application of Machine Learning Approaches for Classifying Sitting Posture Based on Force

and Acceleration Sensors. *BioMed Research International*, 2016.
<https://doi.org/10.1155/2016/5978489>

Table 1: Anthropometric and demographic features of the participants. Values are expressed as mean \pm SD

Age (yr.)	45.8 \pm 6.2
Height (cm)	172.1 \pm 6.2
Body Mass (kg)	79.5 \pm 9.9
Body Mass Index (kg m⁻²)	26.9 \pm 4.1
Experience (yr.)	17.4 \pm 5.8

Table 2: Slopes (a), intercepts (b) and Pearson product moment correlation coefficient between time shift and sway parameters ($\dagger p < 0.05$, $\ddagger p < 0.01$)

	Parameter	r	a	b
Time vs.	Sway Area	0.864 [‡]	213.66	35197.00
	Sway Path	0.727 [†]	26.61	16629.00
	COP displacement in AP direction	0.930 [‡]	0.31	34.88
	COP displacement in ML direction	0.892 [‡]	0.31	60.39
	EC velocity	0.844 [‡]	0.01	2.45
	EC AP velocity	0.823 [†]	0.01	2.35
	EC ML velocity	0.772 [†]	0.01	6.51
	EC coordinate in AP direction	0.807 [†]	0.09	150.23
	EC coordinate in ML direction	0.657	0.04	237.48

Table 3: Slopes (a) and intercepts (b) of Perceived Discomfort rating curves over time

	Perceived Discomfort	a	b
Time vs.	<i>Upper Back</i>	<i>0.004</i>	<i>1.792</i>
	<i>Lower Back</i>	<i>0.002</i>	<i>1.742</i>
	<i>Buttock Area</i>	<i>0.004</i>	<i>1.717</i>
	<i>Sitting Bones</i>	<i>0.004</i>	<i>1.591</i>
	<i>Edge of Seat Contact</i>	<i>0.006</i>	<i>1.550</i>
	<i>Overall Discomfort</i>	<i>0.041</i>	<i>7.717</i>

Figure 1.

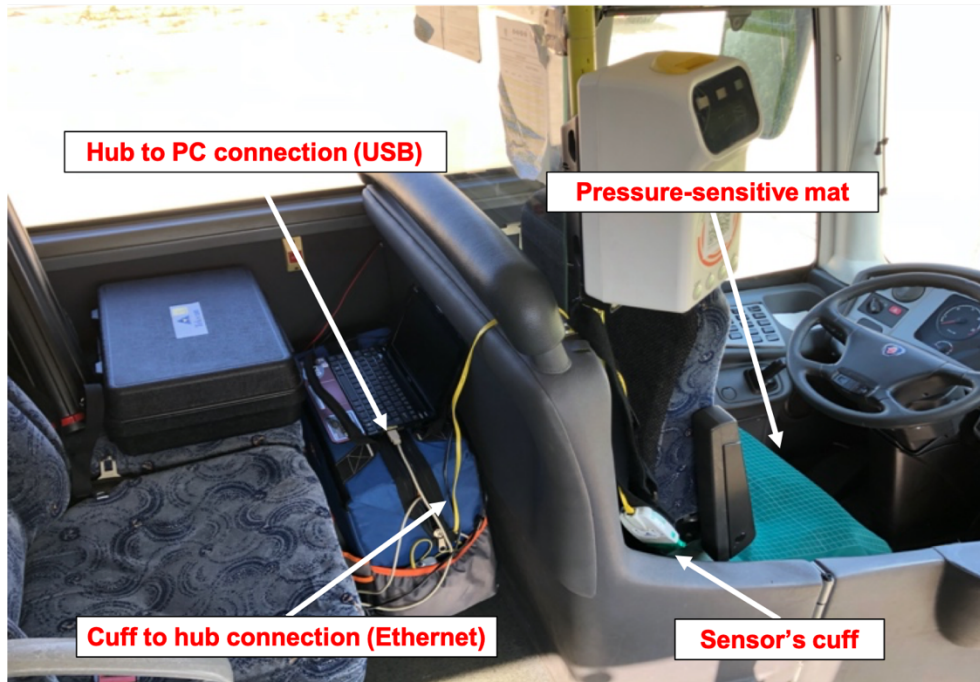


Figure 2



Figure 3

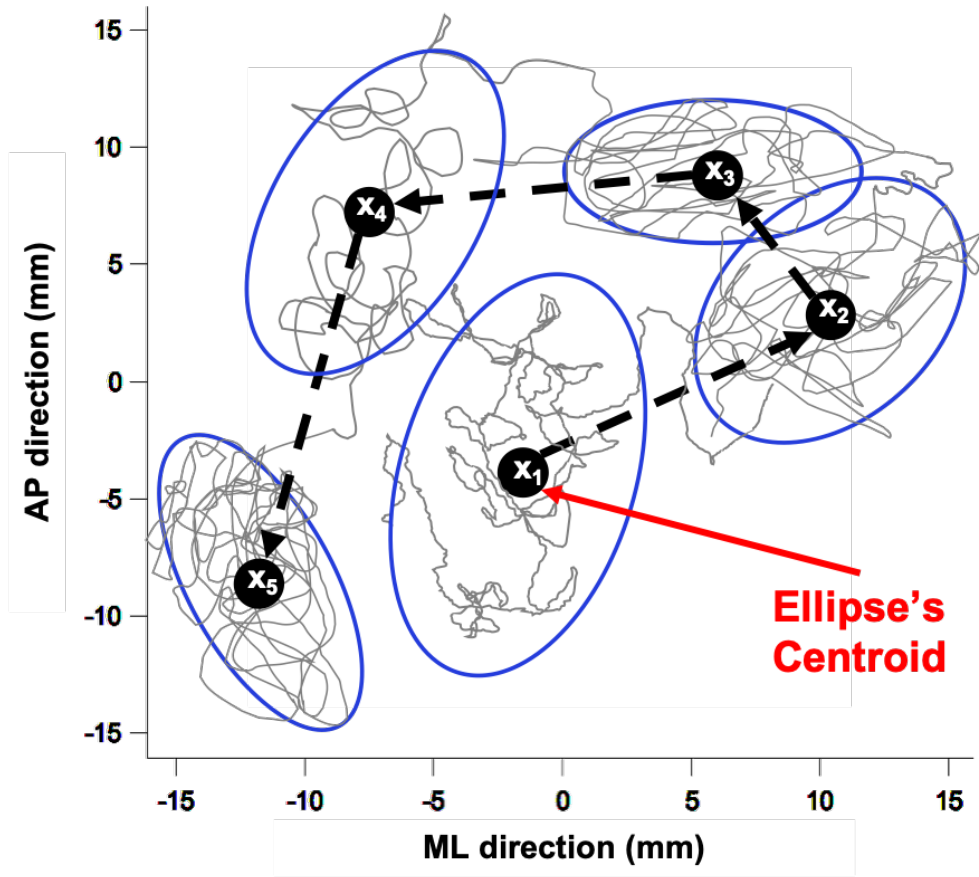


Figure 4

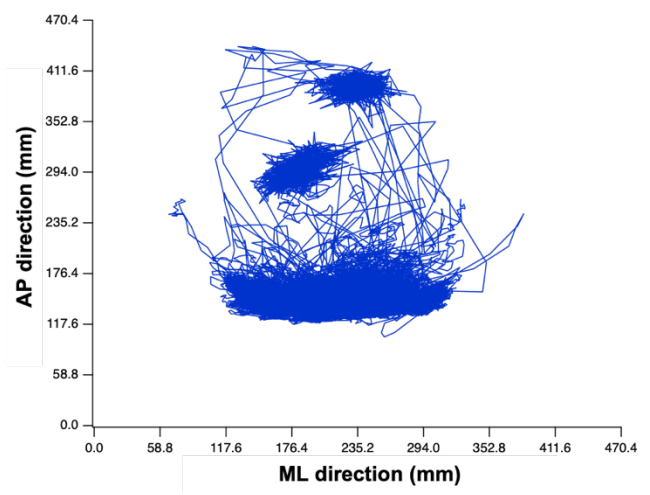
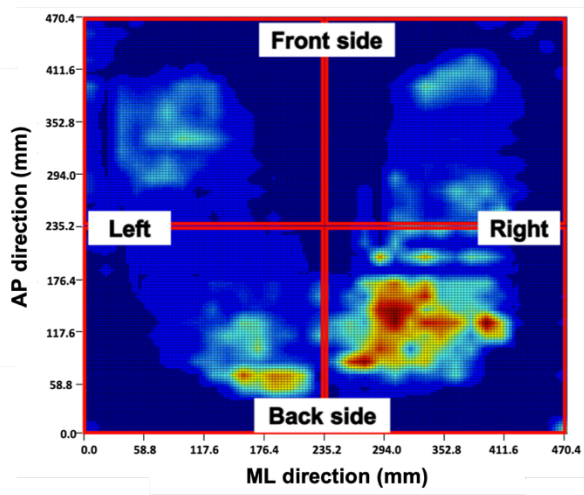


Figure 5

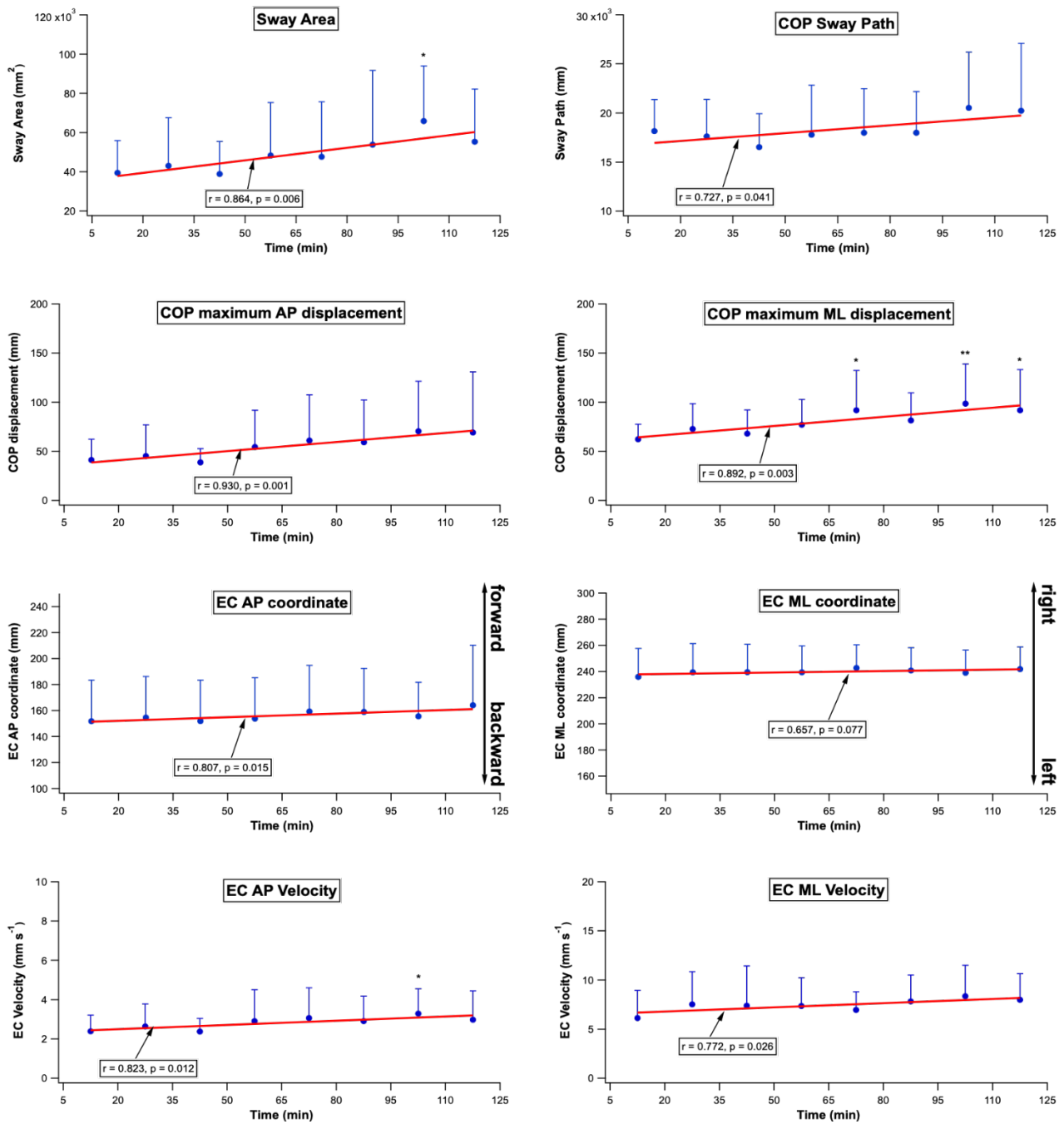
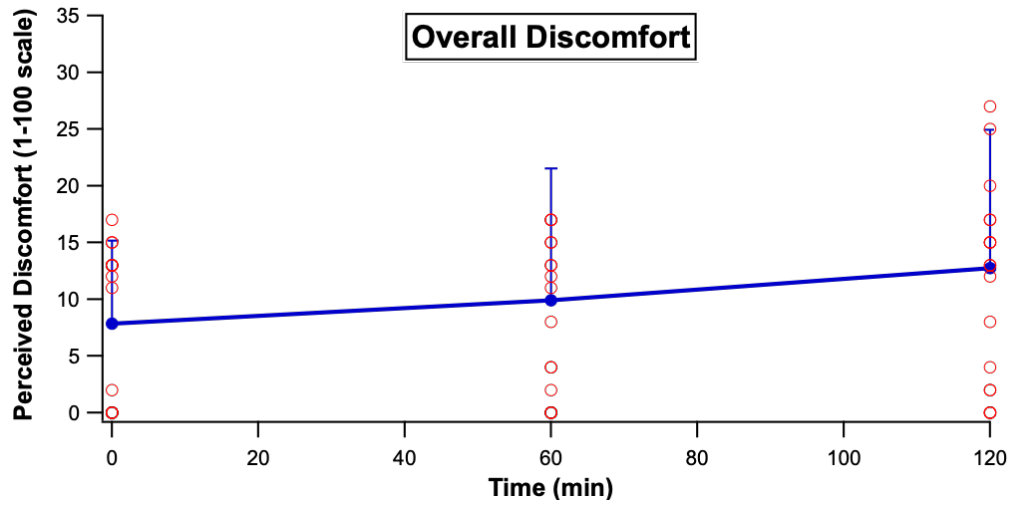


Figure 6.



Figures Captions

Figure 1: Photo of the pressure-sensitive mats positioned on the seat and connected to the computer.

Figure 1 Alt-text: The picture shows the experimental setup located in the bus cockpit. The pressure-sensitive mat, which is firmly attached to the seatpan, is connected to a 2-port hub by means of an Ethernet connection. Incoming pressure data from the hub is then transferred to a notebook by means of a USB connection.

Figure 2: Bus driver during an experimental session.

Figure 2 Alt-text: This photo shows the driver position during the experimental tests while the sensor is collecting body-seat pressure data.

Figure 3: A qualitative example on the information provided by the Ellipse's Centroid (EC) coordinates and EC velocity. EC coordinates are calculated every 2.5 seconds (x_i) and EC velocity is defined as the EC displacement between two consecutive windows divided by the time.

Figure 3 Alt-text: This diagram, which reports the displacements of the COP in ML direction in x-axis and in AP direction in y-axis, shows an example of the relationship existing between the COP sway path, the sway area and the ellipse's centroid (EC). In particular, data of five consecutive windows are represented, with five different ellipses (containing the 95% of the COP sway path) and five centroids. The distance between each centroid is also represented by means of an arrow, which describes the path followed by the EC.

Figure 4: On the left, an example of pressure distribution in the seatpan: left and right, front and back sides are identified with the four quadrants. On the right, an example of the EC path during the entire trial.

Figure 4 Alt-text: On the left, it is reported an example of the body-seat contact pressure distribution on the seatpan during an experimental test, represented as false-colour scale map. The body region characterized by the highest pressure values (i.e., ischiatic tuberosities) appear as yellow-red, while those at low pressure are blue. Four quadrants identify the different body regions of interest (right and left thigh and gluteus). The diagram on the right (displacements of the COP in ML direction in x-axis and in AP direction in y-axis) shows the COP sway path referred to the entire 120 minutes session. In particular, it is possible to discriminate three different regions of the seatpan around which the COP mainly moves during the shift.

Figure 5: Trends of outcome variables over time. Error bars indicate standard deviations, and the symbols * and ** indicate a significant difference vs. baseline value ($p < 0.05$ and $p < 0.01$, respectively).

Figure 5 Alt-text: This figure reports eight graphs which show the trend of the investigated parameters (sway area, COP sway path, COP maximum displacements, EC coordinates, EC velocity) over the 120 minute sessions. Trend lines, along with Pearson's coefficient and p value, show that all parameters except for the EC ML increase significantly over time.

Figure 6: Trend of overall perceived discomfort over time. Red circles indicate perceived discomfort for each subject, blue line and dots represent the average value. Error bars indicate standard deviations.

Figure 6 Alt-text: The graph shows the increasing trend of Overall Perceived discomfort over time. Blue line and markers refer to the mean value of all subjects, red dots represent the value for each participant.