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The effect of an active steering system on city bus drivers' muscle activity

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City bus drivers spend hours driving under time pressure, in congested traffic and in a monotonous sitting position. This leads to unhealthy working conditions, especially in terms of physical and psychological stress. The aim of this study is to investigate whether an active steering system can alleviate the musculoskeletal stress involved in manoeuvring a bus. Twenty bus drivers drove a city bus equipped with the Volvo dynamic steering (VDS) support system in real traffic. Steering effort was evaluated with electromyography and with a questionnaire. Compared to baseline, VDS significantly reduced the required muscle activity by on average 15–25% while turning, and up to 68% in the part of the manoeuvre requiring maximum effort. The bus drivers believed that VDS will help reduce neck and shoulder problems, and they expressed a desire to have VDS installed in their own bus.

Keywords: active steering; electromyography; city bus driver

1. Introduction

Bus drivers' working conditions have changed over the last 10–20 years, showing an increased pressure to provide efficient public transportation at low cost. The many external pressures on bus drivers in combination with little control over their working environment make bus driving a classic example of a high-stress occupation with a direct impact on bus drivers' health [1]. Apart from psychological stressors (depression, anxiety, post-traumatic stress disorder) and behavioural outcomes (e.g., substance abuse), there is also a need to improve the physical working environment to maintain healthy and happy bus drivers [2]. In a recent study, Taklikar [3] reported that 79% of bus drivers had lower back problems, 15% had neck pain and 5% had shoulder pain. Postural stress and long-term exposure to whole body vibrations have been identified as key factors contributing to lower back problems among bus drivers [4,5].

A contributing factor to the musculoskeletal problems that arise when driving a bus is that it is physically demanding to manoeuvre and steer the bus [6]. For this reason, heavy vehicles such as buses, coaches and trucks are sometimes equipped with active steering support systems. Such systems allow for a more ergonomic working environment through self-centring of the steering wheel, by improved directional stability and by reducing vibrations in the steering wheel. The direction stability is of great value for coaches that are mainly operating on highways and in intercity traffic, whereas self-centring is supportive in urban environments, with more roundabouts and complex traffic situations. The overall goal with active steering is to provide a working situation where the driver can manoeuvre the bus with less effort and hence reduced muscle tension [7,8]. The extent to which active steering actually reduces muscle tension is not known.

Surface electromyography (EMG) provides a non-intrusive way of measuring muscle activation [9]. EMG is therefore an appropriate technique when assessing active steering systems and the effort involved in steering. Previously, EMG recordings have been used to assess the function of the muscles of the upper limbs in car driving [10–12]. The main findings are that the prime movers are primarily a consequence of steering direction while the stabilizing or fixating muscles are primarily constant, and that muscle activation depends strongly on both steering rotation and steering torque [12]. The key muscles correlated to steering are the triceps brachii, deltoids, pectoralis major and infraspinatus, while the main stabilizing or fixating muscles are the pectoralis major, triceps brachii, biceps brachii and teres major [11,12].

The aims of this study are to investigate to what degree an active steering system reduces the amount of muscle activity needed to manoeuvre a bus and to collect users' opinions and experiences about such systems.

2. Materials and methods

2.1. Participants

Twenty city bus drivers (15 males and 5 females) participated in the study. Their mean age was 47 years (*SD* 10)

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with a mean height of 177 cm (*SD* 9). On average, they drove 51,390 km/year (*SD* 15,331). On a 6-point scale (1 = *never* to 6 = *every day*), the drivers reported whether they had troubles with sore joints (*M* 1.9, *SD* 1.1), stiff, tense or sore muscles (*M* 2.1, *SD* 1.1), ache in the lower back (*M* 2.4, *SD* 1.2), pain in joints, arms or legs (*M* 2.4, *SD* 1.2) and pain in the neck (*M* 1.9, *SD* 1.1). On a question asking whether they had any of these issues at the day of the experiment, all drivers answered no.

The drivers received the equivalent of EUR 50 in compensation. The recruitment of bus drivers took place via advertisement in social media and via announcements at several public transport companies in the Gothenburg area, Sweden. The study was approved by the Regional Ethical Committee in Linköping, Sweden (EPN 2016/172-31).

2.2. *Procedure*

Upon arrival, the drivers received information about the aim of the study. Their driving licence was checked, and the blood alcohol concentration was controlled with a breathalyser to make sure that they were not under the influence of alcohol. The participants were asked to sign an informed consent form and to fill in a background questionnaire. The last step before proceeding to the bus was to attach disposable electrodes for the EMG measurements. After the trial, the participants provided feedback about the active steering system via a questionnaire. The entire procedure took about 1.5 h.

The study had a within-subject design where the drivers drove two laps on a 20-min route. The order of the two conditions was balanced, where half of the drivers drove the active steering condition followed by the baseline condition whereas the other half drove the baseline condition followed by the active steering condition. Whether active steering was activated or not was known by the drivers.

To get familiar with the route, with the bus and with the active steering system, a practice lap was driven before the actual experiment started. The active steering system was active during the first half of the practice lap and turned off during the second half.

The trials were conducted on public roads with driving speeds up to 70 km/h, partly in an industrial area with low traffic density. The route included roundabouts and several intersections where the drivers either turned left or right. The results reported in this article are derived from three roundabouts, five right-hand turns and three left-hand turns. All manoeuvres were conducted in locations where the driving speeds were relatively low; *M* 14 km/h (*SD* 6).

2.3. *Equipment*

The bus used in the trials was a Volvo model 8900 (Volvo Bus Corporation, Gothenburg, Sweden). The active steering system under investigation was the Volvo dynamic steering (VDS) system. VDS is based on a conventional mechanical steering system where the steering wheel is connected via a steering shaft to a steering gear. The hydraulic servo system in the steering gear is generating the force needed to steer the front wheels of the bus. VDS utilizes an electronically controlled electrical motor situated on the steering shaft, situated on the angle gear on the vertical steering shaft (Figure 1). The electrical motor works on top of the hydraulic assistance and provides extra support for the driver. The motor control is collecting and acting on data from the vehicle 2000 times/s, including vehicle speed, steering wheel torque and angle. Disturbances from the road are detected and compensated for. This means that the disturbances are not transferred through the motor and are therefore not affecting the driver. Steering support is also adapted to vehicle speed. At low speeds, the bus is easy to steer, and at higher speeds, steering becomes firmer, leading to a high level of directional stability. In heavy vehicles, the steering geometry does not always provide the forces needed to return the steering wheel to the centre position, as on a passenger car. With VDS, steering wheel return is generated by the electrical motor, helping the driver to actively head straightforward. This is also the case when driving in reverse, which is normally not possible due to steering kinematics.

Figure 1. Schematic illustration of VDS.
Note: VDS = Volvo dynamic steering

In the bus that was used in the experiments, VDS could easily be switched on or off. This means that the seating position and the geometry of the steering wheel were identical in the baseline condition and in the condition with active steering.

The bus was equipped with a data acquisition unit (VBox; RaceLogic, UK) connected to the controller area network of the bus to measure vehicle dynamics along with GPS data. The sample rate was 10 Hz. Two video streams were also recorded, one showing the forward roadway and the other showing the driver.

Muscle activity was recorded by a Vitaport 3 system (TEMEC Instrument, The Netherlands) using pregelled Ag/AgCl electrodes. The electrodes were positioned according to the ‘Surface electromyography for the non-invasive assessment of muscles’ (SENIAM) guidelines [13] over the belly of the left and right biceps brachii, the left and right triceps brachii, the left and right superior part of the trapezius and the left and right lateral part of the deltoids (see Figure 2). These muscles were chosen based on previous studies on upper limb movements in car driving [11,12], but excluding muscles that cannot be reliably recorded in real-life driving where the driver is moving around. For example, it is difficult to obtain high-quality data from EMG electrodes on the back since the driver is leaning against the seat. Similarly, it is difficult with electrodes on the chest because of the seat belt.

The inter-electrode distance was 2 cm. The reference electrode was positioned at the left wrist. The skin beneath the electrodes was gently rubbed with conductive cleaning paste, and the cables and electrodes were fixed with adhesive tape to relieve strain from accidentally pulling the cables while manoeuvring the bus. The EMG signal was high-pass filtered at 10 Hz, low-pass filtered at 500 Hz and sampled at 1024 Hz. Time synchronization between the Vbox and the Vitaport was achieved by a manual trigger connected to both systems.

After both drives, the participants were asked ‘If you drive a bus with VDS, how do you think you would experience the following compared to if you were driving a bus without VDS?’ The answers were given on a 5-point scale (from 1 = *less* via 3 = *no difference* to 5 = *more*). The items to be rated were headache, stiff/tense neck, stiff/tense shoulders, stiff/tense lower back, stiff/tense upper back and pain in the arms/shoulders that radiates to the neck. The drivers were also asked to rate, on a 6-point scale (from 1 = *no benefit* to 6 = *great benefit*), whether they foresaw that the system would be beneficial when negotiating curves, on uneven roads, at intersections, at roundabouts and at bus stops. They were also asked whether they would like to have VDS in their own bus.

2.4. *Data preparation*

The purpose of the EMG recordings was to investigate to what degree VDS reduced the amount of muscle activity needed to manoeuvre the bus. This was analysed by comparing the EMG amplitudes in the two conditions, within the same muscle and participant and without removing the electrodes between the recordings. Before comparing the amplitudes, the EMG signals had to be de-noised, normalized and synchronized.

Independent component analysis (ICA) in combination with high-pass filtering was used to remove electrocardiogram (ECG) contamination from the EMG signals [14]. ICA decomposes a set of time series (here the eight EMG channels) into a set of statistically independent source signals. Assuming that the ECG is statistically independent from the EMG data, the ICA decomposition will isolate the ECG signal in one or possibly a few of these source signals. The sources containing ECG data were identified by visual inspection and de-noised using a fourth-order Butterworth high-pass filter with a cut-off frequency of 30 Hz [15]. After de-noising the ECG components, the EMG signals were reconstructed by projecting back all components into the original signal space, resulting in clean EMG signals without ECG interference. The second-order blind identification (SOBI) method was used to perform the ICA decomposition due to its effectiveness of separating mutually uncorrelated sources that are internally correlated [16].

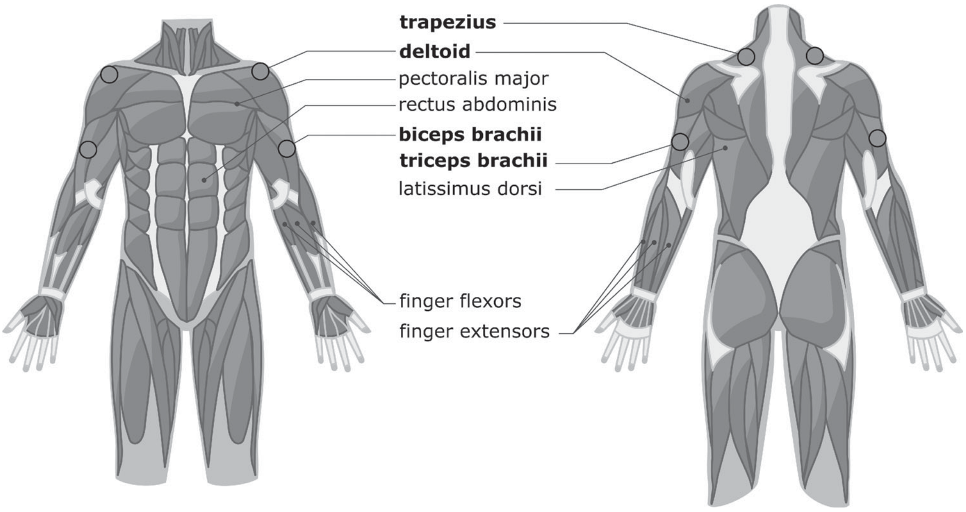

Figure 2. Anterior and posterior muscle chart.
Note: The eight muscles included in the study are marked in bold font. The EMG electrode positions are highlighted with circles. Image adapted from an original illustration from Thinkstock (http://www.thinkstockphotos.com), with permission. EMG = electromyography.

The EMG signals from each participant were normalized by dividing with the median of the 500 largest peaks in the EMG after full wave rectification (this is similar to the standard EMG approach of normalizing the data to the range [−1, 1], by dividing with the maximum value [17], but more robust to outliers and noise). Since different EMG amplitudes are expected in the baseline condition compared to the VDS condition, the 500 peaks were extracted from a merged EMG where the baseline data and the VDS data were concatenated. Both the baseline EMG and the VDS EMG were then divided by the same median value.

The normalized EMG envelope was extracted by full wave rectification followed by spline interpolation over local maxima separated by at least 50 ms (this is similar to the standard EMG approach of low-pass filtering the rectified signal to achieve a smooth envelope [17], but again more robust to outliers and noise). The EMG envelope was then used as a measure of muscle activity.

The recorded muscle activity varies from manoeuvre to manoeuvre and from participant to participant due to slightly different timing but also due to differing steering strategies. By and large, muscle activation thus varies with the road layout and particularly with the location of the bus along the road. EMG data were therefore synchronized across participants based on the recorded GPS coordinates. The purpose of this pre-processing step was to re-reference the acquired time series to a geospatial coordinate system, meaning that muscle activity was represented as a function of location instead of as a function of time. This made it easy to select and compare data across trials and participants.

EMG data with two different spatial resolutions were used in the analyses. Descriptive analyses and many of the graphs were derived using a sample rate corresponding to 10 Hz (we write corresponding since the data are not sampled as a function of time in the geospatial coordinate system). For statistical analyses, the EMG data traces were averaged across each manoeuvre type based on data ranging from 50 m before the turn to 50 m after the turn. All pre-processing was conducted in MATLAB version 9.0.

Manual video annotations were performed to derive information about how the bus drivers used their hands, with special focus on the turning phase and the phase when the driver steered back after the turn.

2.5. *Statistical analysis*

Three different manoeuvre types were included in the statistical analyses: turning left at roundabouts, turning right at intersections and turning left at intersections. Along the route, there were three roundabouts, five right-hand turns and three left-hand turns.

Mixed-model analyses of variance (ANOVAs) were used to compare the muscle activity with and without VDS activated and to evaluate potential differences between turning manoeuvres. The model included main and two-level effects with VDS (baseline/active) and manoeuvre (turning left at roundabout, turning right and turning left). The participant (1–20) was included as a random factor. The dependent variable was the mean muscle activity. Eight separate ANOVAs were used to analyse the different muscle groups separately. The significance level was set to 0.05, and Bonferroni correction was used to compensate for multiple comparisons. The assumption of normality was checked using the Lilliefors test on the residuals of the data.

Based on the video annotations, a χ^2 test was used to analyse potential differences between baseline and VDS in terms of how many hands the driver used to steer the bus. Another χ^2 test was conducted to analyse the steering back phase (active steering, passive steering just letting the steering wheel glide though the hands or passive steering using no hands at all in the self-centring phase). Descriptive statistics were used to analyse the questionnaire data. All statistical analyses were performed using SPSS version 22.0.

3. Results

3.1. *Effect of active steering on muscle activity*

The amount of muscle activity needed to perform the three different manoeuvres is illustrated in Figure 3. There was a significant difference between the baseline condition and driving with VDS for all muscles except for the left deltoid (Table 1). The manoeuvre type had a significant impact on muscle activation for all muscles except the left triceps and the right biceps. There were no significant interactions between manoeuvre type and VDS activation, except for the left deltoid.

The differences in muscle activation between baseline driving and driving with VDS are summarized in Table 2. The mean difference in the left part of Table 2 represents the mean value across all participants and all EMG data points in the manoeuvre per muscle. The overall reduction in EMG muscle activity was 19% when VDS was active. Averaging across participants, across muscles and over an entire manoeuvre, however, will underestimate the difference between baseline and VDS. This is a consequence of different muscles being activated in different parts of the manoeuvre, and the average includes data from both contraction and relaxation. Therefore, the maximum difference of the EMG data points in the manoeuvre, averaged across participants, was also derived. This measure provides a better representation of muscle activity derived from data where the muscle is actually used. Here, the overall reduction in the amount of EMG muscle activity was 57%, with reductions of up to 68% for individual muscles in certain manoeuvres (Table 2).

Figure 4 shows an example of muscle activity averaged across all participants and all muscles for a right-hand

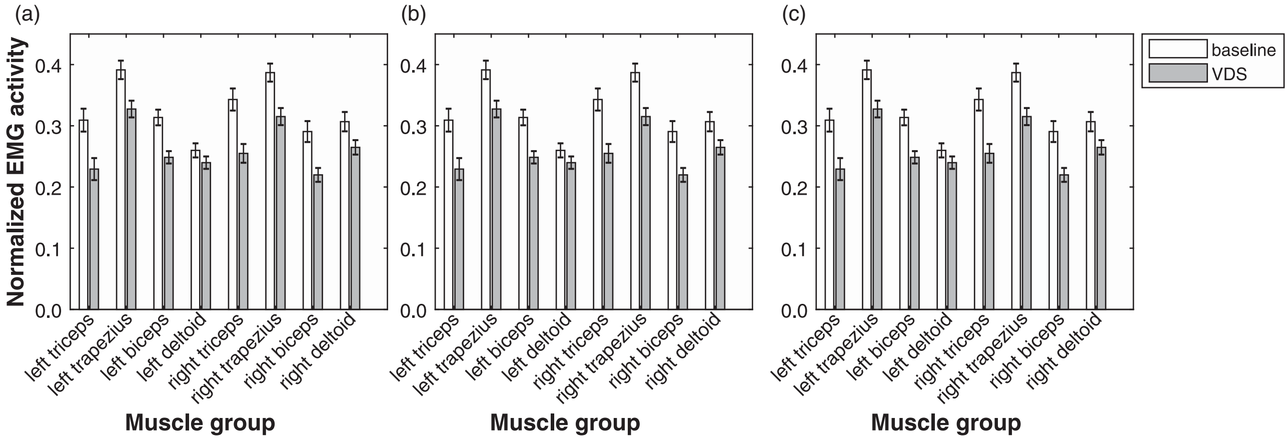

Figure 3. Summary of the mean muscle activity needed when turning (a) left at a roundabout, (b) right at an intersection and (c) left at an intersection.

Note: Mean value is calculated across all participants and all manoeuvres, and error bars represent the standard error of mean. EMG = electromyography; VDS = Volvo dynamic steering.

Table 1. *F*, *df* and *p* values from a mixed-model ANOVA comparing muscle activity with and without VDS activated and differences between turning manoeuvres (turning left at roundabout, turning right at intersection and turning left at intersection).

	VDS	Manoeuvre
Muscle	$F(1, 373–378)$ (p)	$F(2, 371)$ (p)
Left triceps	82.68* (<0.001)	3.26 (0.039)
Left trapezius	41.22* (<0.001)	8.69* (<0.001)
Left biceps	80.12* (<0.001)	42.29* (<0.001)
Left deltoid	3.18 (0.076)	6.75* (0.001)
Right triceps	68.09* (<0.001)	34.11* (<0.001)
Right trapezius	38.50* (<0.001)	7.04* (0.001)
Right biceps	58.69* (<0.001)	2.85 (0.059)
Right deltoid	41.83* (<0.001)	24.91* (<0.001)

*Significant values, after Bonferroni correction (corresponding to $p < 0.006$).

Note: ANOVA = analysis of variance; VDS = Volvo dynamic steering.

turn. It can be seen that during baseline, muscle activity is required both when entering the intersection and also when aligning the bus by steering back after the turn (Figure 4a). When VDS is activated, the amount of muscle activity needed when entering the intersection is lower and there is no need to steer back after the turn (Figure 4b). This is also shown in Figure 5, where the mean amount of muscle activity per muscle is plotted as a function of distance driven (in the same right-hand turn as was illustrated in Figure 4). The first peak in Figure 5a is the actual steering phase whereas the second peak shows the steering back phase when aligning the bus. The left triceps is used to pull the steering wheel counter-clockwise when steering back. It is also used to push the arm forward and to stabilize the clockwise steering wheel movement when entering the intersection. VDS removes the need to use the left triceps when steering back. The right triceps is used in a similar way but to a lesser extent (Figure 5b). The left and right trapezius muscles are used for pushing/pulling the

Table 2. Mean and maximum percentage difference in EMG muscle activity per muscle and per manoeuvre type (turning at roundabout, turning right and turning left at intersection).

	Mean difference			Maximum difference		
Muscle	Roundabout (%)	Right (%)	Left (%)	Roundabout (%)	Right (%)	Left (%)
Left triceps	25.9	19.7	32.7	59.6	56.6	59.2
Left trapezius	16.3	13.5	19.8	50.8	49.6	51.2
Left biceps	20.8	25.9	26.4	62.2	58.6	56.6
Left deltoid	7.7	−5.6	25.8	55.7	49.1	64.8
Right triceps	25.7	25.5	19.4	65.2	57.2	53.2
Right trapezius	18.6	16.0	16.5	51.4	54.3	53.5
Right biceps	24.4	15.4	27.1	67.8	56.2	62.7
Right deltoid	13.7	16.4	9.8	58.0	55.9	53.5
Overall	19.1	15.9	22.2	58.8	54.7	56.9

Note: EMG = electromyography.

Figure 4. The full colour version of this figure is available online. Mean EMG amplitude across all drivers and all measured muscles for a right-hand turn during (a) baseline and (b) when VDS is activated.
Note: The trajectory is colour coded according to the amount of muscle activity used. Note that when VDS is activated, almost no muscle activity is required in the turning back manoeuvre after the turn. The arrow shows the direction of travel.
EMG = electromyography; VDS = Volvo dynamic steering. The full colour version of this figure is available online.

steering wheel, but mostly to support the arm movement (Figure 5c,d). The left biceps is used to pull the steering wheel counter-clockwise when steering back after the turn, and it is also used to stabilize the initial steering manoeuvre (Figure 5e). The right biceps is mainly used to pull the steering wheel clockwise, and is not really used when steering back after the turn (Figure 5f). For the deltoids, the left and right sides have more or less alternating muscle activations since the deltoids are activated when moving the hand forward (the left and right hand are on the opposite sides of the steering wheel so when left deltoid contracts the right deltoid relaxes) (Figure 5g,h).

3.2. *Steering wheel behaviour based on video analysis*

The video analysis focused on how the bus drivers used their hands in the three manoeuvres, with special focus on the turning phase and the phase when the driver steered back after the turn. The results show that there was no significant difference between baseline and VDS in the initial steering phase, regarding whether the driver had one or two hands on the steering wheel. In the turning back phase, significantly more drivers used only one hand when VDS was active ($\chi^2 = 7.22$, $p = 0.007$). Further video analyses of the steering back phase showed that 50% of the drivers passively let the steering wheel glide through their hands, or used no hands at all (34%), in the steering back phase. This contrasts with the baseline condition where the drivers actively steered back in 98% of the cases. The difference between baseline and VDS was significant ($\chi^2 = 209.77$, $p < 0.001$).

3.3. *Bus drivers' opinions and experiences about active steering*

Responses to the question 'If you drive a bus with VDS, how do you think you would experience the following compared to if you were driving a bus without VDS?', provided on a 5-point scale (from 1 = *less* via 3 = *no difference* to 5 = *more*), are shown in Figure 6. Especially, problems related to the shoulders were believed to be reduced by an active steering system. The drivers also believed that active steering would be useful in many different situations. On a 6-point scale (from 1 = *no benefit* to 6 = *great benefit*), the drivers foresaw that the system would be beneficial when negotiating curves (*M* 4.6, *SD* 1.27), on uneven roads (*M* 3.7, *SD* 1.71), at intersections (*M* 4.6, *SD* 1.50), at roundabouts (*M* 4.9, *SD* 1.42) and at bus stops (*M* 4.5, *SD* 1.39). All 20 drivers replied that they wanted active steering in their own bus.

4. Discussion

The aims of the present study were to investigate: (a) to what degree active steering reduces the amount of muscle activity needed when manoeuvring a bus; (b) to collect users' opinions and experiences about such systems. The investigated steering support system significantly reduced the work required by the bus driver by about 15–25% in general while turning, and up to 70% in the part of the manoeuvre requiring maximum effort. This is primarily achieved by reducing friction and by improving the reversibility so that the driver does not have to exert

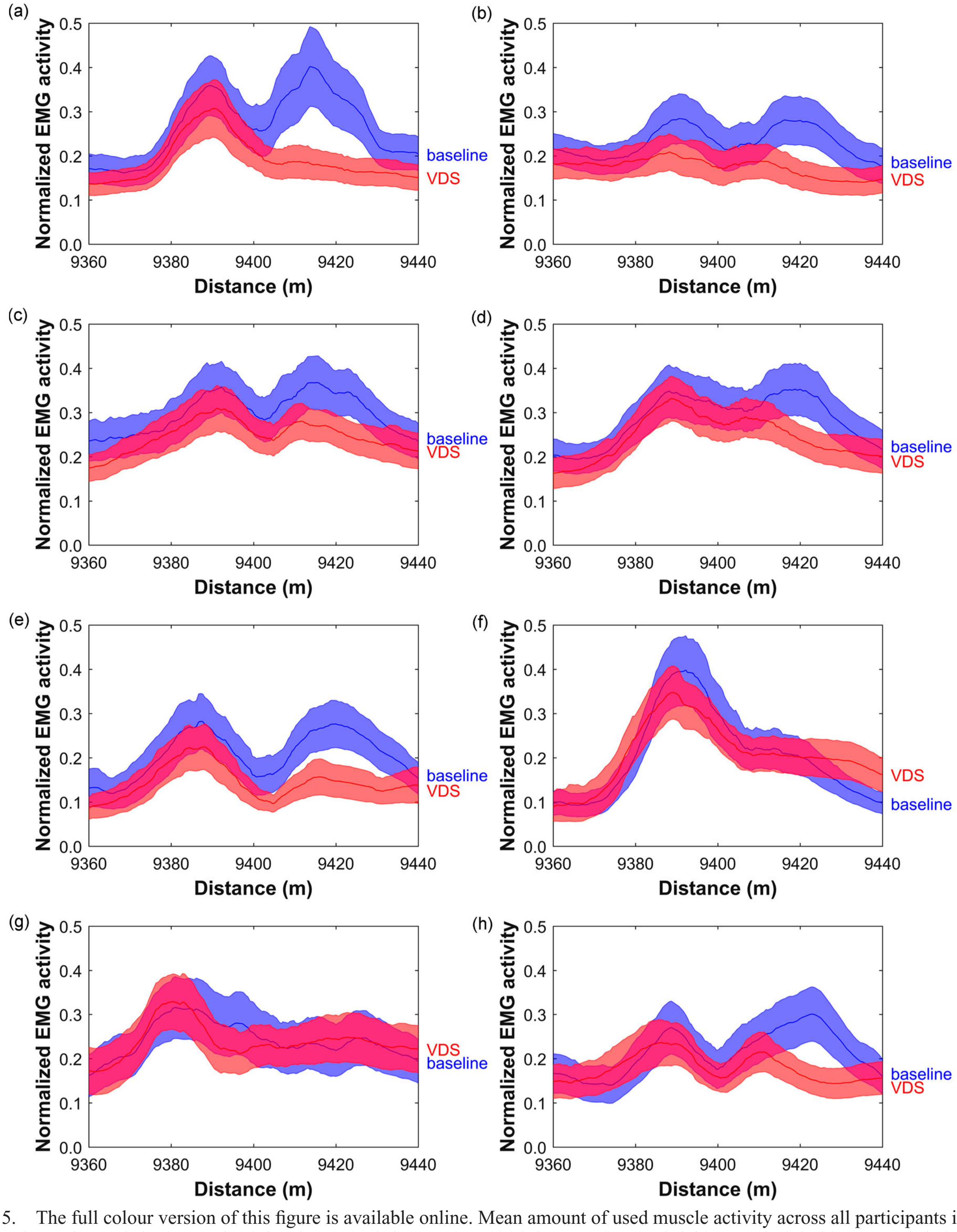

Figure 5. The full colour version of this figure is available online. Mean amount of used muscle activity across all participants in a right-hand turn for (a) left triceps, (b) right triceps, (c) left trapezius, (d) right trapezius, (e) left biceps, (f) right biceps, (g) left deltoid and (h) right deltoid.
Note: Muscle activity is plotted as a function of distance driven along the route. Shaded area represents the standard error of mean. The excerpt corresponds to the right-hand turn in Figure 4. EMG = electromyography; VDS = Volvo dynamic steering. The full colour version of this figure is available online.

effort when returning the steering wheel to the original position.

The self-centring property of VDS is central for the results. Removing the need to steer back after a turn effectively reduce the muscle activity needed to complete the steering manoeuvre. This is particularly valuable at roundabouts since such steering manoeuvres involve several phases including turning both to the left and to the right. Self-centring reduced the effort involved in the transition between these phases. Reducing the muscle strength needed in turning manoeuvres will most probably contribute to reduced strain in the neck and in the shoulders, as expressed by the bus drivers in the questionnaire. Interestingly, the second steering back peak comes earlier in the VDS condition than the corresponding peak in the baseline condition in most graphs of Figure 5. This finding is explained by the functionality of VDS. The driver has to initiate the manoeuvre and then the steering support system takes over. Even though the peak occurs earlier in the VDS condition, the onset of the peak is similar in both conditions.

The steering manoeuvre is a complex movement of the upper limbs, including motions around the shoulder, the elbow and the wrist joints. One muscle can represent fundamentally different functions corresponding to the composite movement during steering. For example, the deltoids can act as agonists in adduction or as antagonists in abduction, and in order to perform a steering manoeuvre the motion around the shoulder joint is composed of abduction (or adduction), extension (or flexion) and supination (or pronation) [12]. In a controlled experimental setting, detailed analyses can be carried out to investigate steering actions and their associated muscle activities from a kinetic and biomechanical point of view [10–12]. Using a controlled setup where the drivers are forced to perform controlled movements according to a strict experimental protocol, however, would not provide a realistic picture of VDS since the system is not used like that in real life. For example, some, but not all, drivers let go of the steering wheel with one or both hands at some point during the steering manoeuvre, and it would be strange for them to do it in a different way. In this study, we therefore chose a more naturalistic setting for the experiment. A direct consequence of this choice is that detailed kinematic analyses cannot be performed since all drivers behave a little differently. Instead, the data were analysed on a more aggregated manoeuvre-by-manoeuvre level (rather than on a movement-by-movement level), providing a more pragmatic view of the usefulness of VDS in real-life driving.

The bus drivers used VDS for the first time in the study. The effects found in this study should therefore be seen as first-encounter effects. Driving a bus with active steering is quite different from driving an ordinary city bus. Even though the drivers could test the system for 10 min before the trials, it is likely that our results underestimate the true gain of VDS. After some time with the system, we expect drivers to learn in which situations it is possible to let the system work for them, and also to be more confident in the functionalities of the system. In time, when the drivers have adapted to the new system, it is therefore likely that active steering can reduce the required physical effort even more than what we have found in this study.

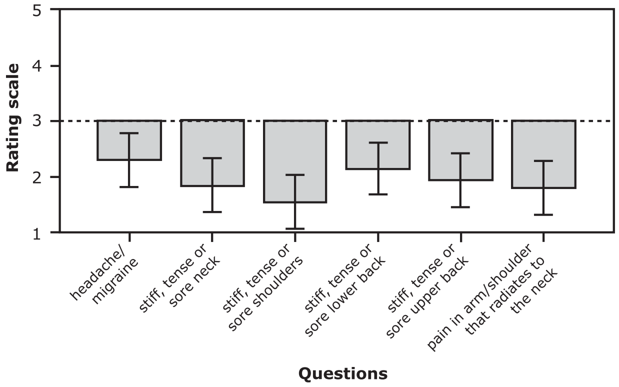

Figure 6. Mean responses to the question ‘If you drive a bus with VDS, how do you think you would experience the following compared to if you were driving a bus without VDS’ on a 5-point scale from 1 = *less* via 3 = *no difference* to 5 = *more*.
Note: Error bars represent 95% confidence intervals of the means. VDS = Volvo dynamic steering.

The number of muscles included in this study was restricted by the eight available channels on the Vitaport system, and were chosen as a compromise between muscle functionality and signal quality. Additional muscles, especially in the upper and lower back, could reveal important information. We did not collect data from these muscles since the driver is usually leaning against the seat, causing motion artefacts and a low signal-to-noise ratio in general. Also, we did not collect data from the latissimus dorsi and pectoralis major, two large muscles that are commonly engaged in steering. The latissimus dorsi was not considered since the EMG signal contained many artefacts (due to pressure and electrode movement when moving while leaning against the backseat). Similarly, data from the pectoralis major were prone to motion artefacts, partly stemming from the seat belt.

There are a few limitations to this study. First, we did not measure or analyse the impact of vibrations propagating up through the steering column. Reducing vibrations is one of the features of VDS, and this property will be investigated in future experiments. Second, this study only concerned muscle activity and compared VDS with baseline in relative terms. It would have been interesting to normalize the EMG data to maximum voluntary contraction and compare the two conditions in more absolute terms. Third, the baseline system had a rather stiff steering system. This is because the bus had a completely new hydraulic steering gear which had not yet been optimized for use in the ‘VDS off’ mode. That said, the forces required for steering in the baseline condition were well within the legal requirements. Fourth, muscle fatigue can be recognized in an EMG signal as an amplitude increase and as a shift towards lower frequencies [18–20]. In the present study, muscle fatigue was not investigated since the trip duration was relatively short and we did not expect the drivers to encounter muscle fatigue. In future studies, it will be important to investigate the effect of steering support on busses in commercial use over an extended period of time. In such experiments, frequency analyses may be of great interest. Here, the focus was on turning manoeuvres, where the self-centring steering wheel has the key role. Over a time period of months or years, it would be very interesting to investigate to which extent steering support reduces problems with pain in the lower back and shoulders.

5. Conclusions

Active steering is a promising technology that requires 15–25% less muscle activity when turning; in some manoeuvres/situations up to 70% less. This reduction provides a more physically relaxing work environment. The drivers themselves say that they believe active steering will reduce pain, especially in the neck and shoulders. The main advantage with active steering for city buses is that it removes the need to steer back after the turn, a manoeuvre that normally requires a great amount of muscle activity.

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