Case Studies

Women in motorsport: A case report of driving posture and performance after double mastectomy

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A B S T R A C T

Introduction: Here we report a case study of an experienced amateur female racing driver (age = 59) with self-reported fatigue of the muscles of the shoulder girdle post bilateral mastectomy and breast reconstruction. This case study describes how adjustment of her driving posture affected measures of muscle fatigue (sEMG) and driving performance (lap-time).
Methods: Bilateral surface electromyographic activity of sternocleidomastoid, cervical erector spinae, anterior deltoid and pectoralis major, angles of inclination of the cervical and lumbar spine in the sagittal plane and lap-times were measured at: 1) baseline, 2) after an initial adjustment of driving posture, and 3) after a readjustment of driving posture. Mean lap-times improved from 136.81 s (SD = 2.12) at baseline to 134.63 s (SD = 1.8) after readjustment.
Results: Both sternocleidomastoid and left cervical erector spinae fatigued more slowly after readjustment but right cervical erector spinae fatigued more quickly. There was no change in the rates of fatigue of either pectoralis major or anterior deltoid.
Conclusion: The improvement in her performance was associated with a change in the posture and movement pattern of her head rather than her shoulder girdle. It is likely that this improved her ability to visually perceive and steer the racing line.

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1. Introduction

Cornering is a critical skill in most forms of motorsport. The steering torque required to turn a vehicle into a corner is primarily generated by anterior deltoid while the sternal part of pectoralis major is the prime mover for the counter torque (Pick & Cole, 2006). Consequently, drivers with a medical condition that affects the activity of anterior deltoid and/or pectoralis major may have reduced cornering performance.

Here we report a case study of an experienced amateur female racing driver with self-reported fatigue of the muscles of the shoulder girdle post bilateral mastectomy and breast reconstruction. The surgical treatment of breast cancer can result in impaired range of motion of the shoulder as well as ongoing shoulder pain and muscle weakness of the upper limb (Rietman et al., 2003). As a result, the activity of shoulder girdle muscles, including pectoralis

major, typically increases (Oskrochi, Lesaffre, Oskrochi, & Shamley, 2016). It is thought that the increase in muscle activity in the setting of post-surgical pain is a functional adaptation to reduce pain by limiting movement (Graven-Nielsen, Svensson, & Arendt-Nielsen, 1997; Oskrochi et al., 2016). Because the driver did not complain of shoulder pain, we hypothesised that her fatigue was a consequence of the driving posture that she had adopted to cope with any perceived or actual limitations in the movement of her shoulder girdle. Since poor driving posture been shown to accelerate muscle fatigue (Bartuzi et al., 2010), we wanted to optimise her driving posture. This case report describes the method that we used to adjust her driving posture and the effect that it had on her driving performance and muscle activity.

2. Methods

2.1. Participant

The driver was a 59-year-old woman with more than 15 years' experience in amateur sportscar racing. The driver provided

informed written consent for the publication of this case study. Ethical approval to publish the case study was sort from and granted by Curtin University Human Research Ethics Committee.

2.2. Design

This is an anecdotal case report.

2.3. Location and equipment

Testing was conducted at the driver's home track. A private race track 4 km in length with eleven right- and eight left-hand corners. The driver was very familiar with the track having completed hundreds of laps over the course of more than five years. The track was cleared of other vehicles during testing. The race car used was a Porsche 944 prepared to Sports Car Club of America specification. It was fitted with a 10 Hz GPS tracking Unit (Catapult Optimeye S5, Catapult Sports, Docklands, Australia) to obtain lap times and track position.

The driver was fitted with wireless surface electromyography (sEMG) sensors with integrated inertial measurement units (IMUs) (Delsys, Trigno IM, Boston, MA, USA). Data were recorded on a logger mounted with the GPS in the race car. The data presented here consists of EMG signals recorded from the left and right sternocleidomastoid (LSCM, RSCM), left and right cervical erector spinae (LCES, RCES), left and right anterior deltoid (LAD, RAD), left and right pectoralis major (LPM, RPM) and the angles of inclination of the cervical and lumbar spine IMUs with respect to gravity. Sensors were sited in accordance with the recommendations of the SENIAM project (Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles) (Hermens et al., 1999). Muscle activity was recorded in millivolts at a rate of 1111 Hz and kinematics was recorded at 148 Hz. The sensors remained in-place until the tests were completed.

2.4. Experimental design and procedures

A pre-test-intervention-post-test design was used. There were seven phases in the procedure: pre-test, rest, adjustment, post-test one, rest, readjustment, post-test two. The pre-test and post-tests were designed to assess the driver's muscle activity in attempting to set her fastest qualifying time.

The tests commenced in the pits. The driver was strapped into her car then the EMG and GPS data loggers were activated and synchronized by a sequence of taps. The driver was asked to assume her driving position and remain still for 30 s to allow for measurement of her position without movement or vehicle vibration. She then started her car and exited the pits to commence the test.

Each test consisted of two warm-up laps, 10 full-pace qualifying laps, and one cooldown lap. The driver rested for two hours in an air-conditioned lounge between tests.

Driving posture was adjusted in the pits with the driver seated in her race car. Federation Internationale de l'Automobile (FIA) approved EC-50 foam sheets (BSCI Energy Impact Systems, Mooresville, NC, USA) were inserted between the driver's back and her seat. The 2.5 cm (1 inch) thick sheets were cut to fit between the side bolsters of her race seat. A single sheet was slid between the driver and her seat whilst she was seated in the car holding the steering wheel. The height of the sheet was adjusted until the bottom of the sheet extended just below the tangent point of the kyphotic curve of her thoracic spine. A second sheet was then added behind her scapulae so that the foam was 5 cm thick between the inferior angle of her scapula and the top of her shoulder. The edge of the second sheet was trimmed so that it blended neatly with the first sheet. The effect of the adjustment was to reduce the

recline angle and curvature of her seat. Once she was comfortable, the driver started the first post-test. A readjustment was performed after the first post-test based on the driver's comments regarding the initial adjustment. This involved removing the second thickness of foam behind her scapulae and trimming the first so that it extended from just below the inferior angle of the scapula to the top of her shoulder. The effect of the readjustment was to restore the recline angle while maintaining the reduced curvature of her spine. Effectively she was now seated in a 'stomach in, chest out' posture. Once she was comfortable, the driver completed the second post-test.

2.5. Data processing

Lap time and track position were extracted from the GPS unit, imported into Delsys EMGworks (Delsys, Boston, MA, USA) and synchronised with the IMU and EMG data.

The angles of inclination of the lumbar and cervical spine IMUs with respect to gravity were averaged over the middle 20s of the 30s measurement window. Data from the rate gyroscope during the corresponding period were visually inspected to confirm that the driver was still. A negative change in angle indicates a more vertical position.

The EMG data was processed according to the method used by Rosalie and Malone (Rosalie & Malone, 2018). EMG data pertaining to the qualifying laps for each test were identified using GPS track position. The raw data were first bandpass filtered with a 4th order Butterworth filter with corner frequencies of 20 Hz and 500 Hz. Then the median frequency of the power spectrum was calculated using a short-time Fourier transform with a window length of 0.125s and a window overlap of 0.0625s. Finally, median frequency data were normalised to the peak median frequency per muscle per test and time normalised from the commencement of the first lap (time = 0) to completion of the tenth lap (time = 1).

2.6. Statistical analysis

Linear growth models were used to compare lap-time and normalised median frequency (NMF) between driving postures (i.e., Original, Adjusted, Readjusted). We employed a progressive modelling strategy similar to the one used by Rosalie and Malone (Rosalie & Malone, 2018). First, separate unconditional linear growth models were fitted to lap-time and NMF for each muscle. If these models suggested that the dependent variable was time dependent, a quadratic trend was added to the model. Model fit was compared using chi-square likelihood ratio tests. If the quadratic model was both significant and a better fit, a cubic trend was added, and model fit was again compared using chi-square likelihood ratio tests. Finally, conditional growth models were constructed based on the unconditional models with the best fit. Two parameters of each conditional model were examined. For the NMF growth curves, the y-intercept was used as a measure of muscle contractile level or workload unmodified by fatigue (Cifrek, Tonković, & Medved, 2000; Roy & De Luca, 1989). An increase in the y-intercept is indicative of an increase in workload. The slope of the fitted growth curve was used as an index of muscle fatigue with a negative slope indicative of fatigue (Cifrek et al., 2000; Roy & De Luca, 1989; Phinyomark, Limsakul, Hu, Phukpattaranont & Thongpanja, 2012). For the lap-time curves, the y-intercept represents the predicted lap-time on lap 1 and slope represents the predicted change in lap-time across the 10 laps.

3. Results

Readjusted was associated with faster lap-times compared to

both *Adjusted* and *Original* However, lap-times were slower in *Adjusted* compared to *Readjusted* (Table 1).

LSCM and RSCM fatigued faster in both *Original* and *Adjusted* compared to *Readjusted* and LCES fatigued faster in *Original* but not *Adjusted*. In contrast, RCES fatigued more slowly in both *Original* and *Adjusted* (Table 2). The rates of fatigue of LSCM and LCES decreased over time in *Original* [LSCM, $b = 27.25$, $t(65922) = 3.11$, $p = .002$, *95%CI* 10.08, 44.43: LCES, $b = 21.83$, $t(65922) = 2.31$, $p = .02$, *95%CI* 3.32, 40.35] but not in *Adjusted* [LSCM, $b = 14.09$, $t(65922) = 1.61$, $p = .11$, *95%CI* -3.05, 31.24: LCES, $b = -5.58$, $t(65922) = -0.59$, $p = .55$, *95%CI* -24.07, 12.91] compared to *Readjusted* (Fig. 1). In contrast, the rate of fatigue of RCES increased over time in *Original* [$b = -66.45$, $t(65922) = -7.48$, $p < .001$, *95%CI* -83.87, −49.03] and *Adjusted* [$b = -20.55$, $t(65922) = -2.32$, $p = .02$, *95%CI* -37.94, −3.15] compared to *Readjusted* (Fig. 1). The rate of fatigue of RSCM was constant across tests. Neither LAD, RAD, LPM nor RPM fatigued differently between *Original* and *Readjusted* but RPM fatigued faster in *Adjusted* compared to *Readjusted* (Table 2).

The workloads of LSCM, RSCM, RAD, RPM were lower in *Original* compared to *Readjusted* while the workloads of RCES, LAD and LPM were higher (Table 2). The workloads of LCES, RCES and LPM were higher in *Adjusted* compared to *Readjusted* while the workloads of LAD, RAD and RPM were lower (Table 2).

4. Discussion

The magnitude of the improvement in the driver's performance in *Readjusted* was unexpected. The differences in the inclination of the driver's cervical and lumbar spine between *Readjusted* and *Original* were only approximately 1° and 4° respectively, but she completed the *Readjusted* laps 20s faster than the laps in her *Original* posture. . We expected that a change in posture leading to an improvement in performance would be associated with decreased fatigue in the driver's shoulder girdle because these muscles are exerting the force required to steer the vehicle (Bartuzi et al., 2010; Pick & Cole, 2006). However, the improvement in her lap-times was not associated with changes in the rates of fatigue of LAD, RAD, LPM or RPM despite significant changes in the workload of the shoulder girdle in *Original* compared to *Readjusted*. Rather, the improvement in her performance was associated with decreased fatigue of LSCM, RSCM and LCES and increased fatigue of RCES. Interestingly, the workloads of right pectoralis and anterior deltoid were higher in the faster *Readjusted* posture while the

Table 1
Lap time in seconds with respect to driving position for the case study driver. Cervical and lumbar angles are expressed in terms of degrees from vertical.

Lap	Original	Adjusted	Readjusted
Lap time			
1	136.02	138.08	137.86
2	135.90	136.79	136.61
3	136.57	139.80	136.40
4	136.15	138.62	135.35
5	139.80	138.28	133.54
6	140.33	139.17	133.64
7	135.26	138.14	133.46
8	138.62	135.86	133.89
9	133.57	137.07	132.88
10	135.87	135.82	132.66
Mean	136.81	137.76	134.63
SD	2.12	1.34	1.80
Position			
Cervical angle	41.85	37.63	40.41
Lumbar angle	29.97	27.30	33.68

Table 2
Muscle workload and linear fatigue for the case study driver compared to the Readjusted driving position.

Muscle	Position	b	SE b	df	t	Sig.	95% CI	
Workload								
LSCM	Original	−2.80	0.44	65922	−6.44	<.001	−3.67	−1.96
	Adjusted	−0.45	0.43	65922	−1.04	0.301	−1.306	0.40
RSCM	Original	10.54	0.24	65922	43.73	<.001	10.07	11.02
	Adjusted	0.41	0.24	65922	1.70	0.090	−0.06	0.88
LCES	Original	−0.70	0.47	65922	−1.49	0.135	−1.62	0.22
	Adjusted	3.64	0.467	65922	7.77	<.001	2.72	4.56
RCES	Original	4.04	0.44	65922	9.15	<.001	3.17	4.91
	Adjusted	3.13	0.44	65922	7.10	<.001	2.27	3.99
LAD	Original	2.43	0.55	65922	4.45	<.001	1.36	3.50
	Adjusted	−8.27	0.55	65922	−15.15	<.001	−9.34	−7.20
RAD	Original	−1.59	0.38	65922	−4.17	<.001	−2.34	−0.84
	Adjusted	−5.02	0.38	65922	−13.15	<.001	−5.77	−4.27
LPM	Original	2.32	0.28	65922	8.29	<.001	1.77	2.87
	Adjusted	3.34	0.28	65922	11.91	<.001	2.79	3.88
RPM	Original	−3.05	0.10	65922	−29.41	<.001	−3.25	−2.84
	Adjusted	−0.34	0.10	65922	−3.24	0.001	−0.54	−0.13

Positive values for b *indicate that workload is higher compared to Readjusted.*

Fatigue								
Muscle	Group	b	SE b	df	t	Sig.	95% CI	
LSCM	Original	−9.71	3.77	65922	−2.58	0.010	−17.09	−2.32
	Adjusted	−7.82	3.764	65922	−2.08	0.038	−15.20	−0.44
RSCM	Original	−3.06	0.42	65922	−7.33	<.001	−3.88	−2.24
	Adjusted	−1.25	0.42	65922	−2.99	0.003	−2.07	−0.43
LCES	Original	−11.81	4.07	65922	−2.90	0.004	−19.77	−3.84
	Adjusted	−5.39	4.06	65922	−1.33	0.184	−13.35	2.57
RCES	Original	37.581	3.83	65922	9.83	<.001	30.09	45.08
	Adjusted	7.94	3.82	65922	2.08	0.038	0.45	15.43
LAD	Original	−3.19	4.73	65922	−0.67	0.500	−12.47	6.08
	Adjusted	−1.94	4.73	65922	−0.41	0.681	−11.20	7.32
RAD	Original	3.50	3.31	65922	1.06	0.290	−2.99	9.99
	Adjusted	0.78	3.31	65922	0.24	0.813	−5.70	7.26
LPM	Original	−4.39	2.43	65922	−1.81	0.070	−9.15	0.37
	Adjusted	−2.42	2.42	65922	−1.0	0.317	−7.18	2.33
RPM	Original	−3.05	0.10	65922	0.71	0.478	−0.22	0.48
	Adjusted	−0.34	0.10	65922	−3.74	<.001	−1.02	−0.32

Positive values for b *indicate that linear rate of fatigue is slower compared to Readjusted.*

workloads of the corresponding muscles on the left side were lower. One possible explanation is that the driver altered her upper limb movement pattern in the *Readjusted* posture. However, this cannot be either confirmed or excluded because neither video nor inertial measurements were made of her upper limb movement pattern.

We suspect that the faster rates of fatigue for LSCM and RSCM in *Original* compared *Readjusted* were indicative of a forward head position. During neck rotation, a forward head position is associated with increased activity of sternocleidomastoid contralateral to the direction of rotation along with increased lateral flexion towards the direction of rotation (Kim, 2015). An increase in lateral flexion during neck rotation has also been shown to increase activity of sternocleidomastoid ipsilateral to the direction of rotation (Netto & Burnett, 2006). It is possible that in her original driving position, the driver was tilting her head when looking into corners because of a forward head position. Tilting the head causes an increased sensitivity to roll stimuli which makes a visual scene appear to roll more than it actually is (Young, Oman, & Dichgans, 1975). This may have caused an error in her use of differential motion parallax to accurately locate the position of the apex of the corner which is critical in steering a racing line (Cutting, Springer, Braren, & Johnson, 1992; Land & Tatler, 2001). Reducing head tilt when looking into right hand corners may have improved her accuracy in focusing on the location of the apex (van Erp & Oving,
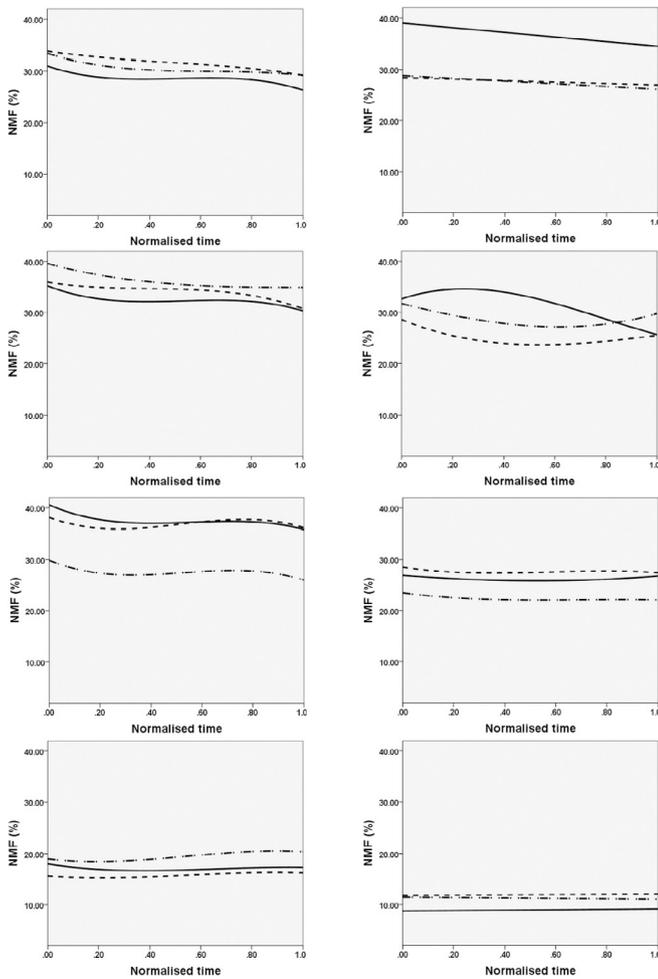
Fig. 1. Fitted conditional growth curves for the case study driver showing the effect of driving position on normalised median frequency of eight muscles. The graphs on the left refer to left sided muscles. Row 1, Sternocleidomastoid; Row 2, Cervical erector spinae; Row 3, Anterior deltoid; Row 4, Pectoralis major. The solid line corresponds to Original, the dash-and-dot to Adjusted and the dashed to Readjusted.

2012) which allowed her to drive faster through corners and improve her lap-time. Again, kinematics of the head were not measured therefore it is impossible to confirm if the driver's head movement differed between postures. However, as shoulder muscle fatigue was unchanged, but neck muscle fatigue was significantly different, on balance it is probable that a change in head movement contributed more to the driver's improved lap-time than a change in upper-limb movement.

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Ethical Statement

Ethics approval to publish this case study was granted by Curtin University Human Research Ethics Committee, Approval number: HRE2017-0850. The participant provided informed written consent to publish her case study.

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