Journal of Expertise
2019. Vol. 2(3)

ISSN 2573-2773

Do Racing Drivers Practice Racing? The Effect of Intentional Following on Formula Car Drivers' Steering Behavior

Simon M. Rosalie[1] and James M. Malone[2]
[1]School of Physiotherapy and Exercise Science, Curtin University, Australia
[2]Raptor Motorsports, USA

Correspondence: Simon Rosalie, simon.rosalie@curtin.edu.au

Abstract

Overtaking in formula car racing often requires close following to gain the benefits of slipstreaming. Research in road driving suggests that following another car closely causes a reallocation of visual attention to a narrower visual search strategy. In formula car racing, drivers' visual search strategy is based on head movement rather than eye movement and is tightly coupled to their steering behavior. Therefore, a change in visual search strategy may affect a formula car driver's steering behavior. We used electromyography to investigate whether skilled amateur formula car drivers ($n = 4$) transferred stable patterns of neck, shoulder girdle, and trunk muscle activation from a task that required them to drive on a clear track to a task that required them to follow another car closely. Rates of fatigue decreased in the muscles of the neck when drivers followed another car suggesting that head movement decreased, consistent with a narrowing of visual search. Concomitant changes occurred in the activation patterns of drivers' shoulder girdle and trunk muscles. The findings imply that the drivers have not practiced following another car sufficiently to maintain stable bimanual coordination patterns for steering when attentional demand is increased in tasks typical of racing. Our results should be taken cautiously because of the small number of drivers tested. However, further studies are warranted to investigate how attentional demands affect formula car drivers' coordination patterns for steering.

Keywords

motorsports, driver error, electromyography, fatigue. visual perception, transfer of learning

Introduction

Formula car racing is a motorsport comprising several disciplines of single-seater, open-cockpit, open-wheel racing. Most formula car race meetings occur over two or three days and involve a series of practice, qualifying, and racing sessions. Importantly, not only do drivers have to complete different tasks in practice, qualifying and racing, but each type of session occurs under different track conditions. In other words, practice/qualifying and racing form a transfer continuum of driving tasks with different environmental constraints across which drivers must transfer their coordination patterns for acceleration, braking, and steering (Müller & Rosalie, 2019; Rosalie & Müller, 2012). For this reason, pre-event and simulator practice should be designed to replicate the task and environmental constraints of each session type to maximize the influence of drivers' pre-existing skills (Newell, 1996; Rosalie & Müller, 2012; Rosalie & Müller, 2014; Seifert, Boulanger, Orth, & Davids, 2015).

The distance that drivers maintain to the car ahead is one of the key differences between practice, qualifying, and racing. In both practice and qualifying, drivers typically maintain a significant gap to the car ahead to avoid the detrimental effects of its aerodynamic wake (Newbon, Sims-Williams, & Dominy, 2017). Effectively, drivers aim to have a clear track ahead during practice and qualifying. On a clear track they know well, racing drivers navigate based mainly on their memory of key landmarks, including corner apexes, which they use to time when to accelerate, brake, and steer (Land & Tatler, 2001). Naturally, such landmarks are fixed which inherently makes their position highly predictable—so predictable in fact, that it is entirely possible for an elite driver to complete a lap of a track they know well “flat-out” while blindfolded. For example, IndyCar driver Alexander Rossi recently completed a simulated qualifying lap of the Long Beach circuit while blindfolded in a time within 0.6 s of his actual 2019 pole position lap time (Jacobs, 2019). In contrast, during a race, drivers often attempt to closely follow the car ahead allowing them to gain a speed advantage from its aerodynamic wake which aids in overtaking (i.e., slipstreaming) (Newbon et al., 2017). Although close following may be advantageous for overtaking from an aerodynamic perspective, the additional attentional load it places on the driver could affect their driving performance. Previous research suggests that when drivers are challenged by the addition of a secondary cognitively demanding task their performance (i.e., lap time) deteriorates (Baldisserri et al., 2014). Critically, Baldisserri et al. (2014) observed that “it seemed that, when approaching the corners of the Monza track, the driver was focused exclusively on the primary task and he started performing the secondary task only after the completion of the manoeuvre (p 61).” This suggests that cornering (i.e., steering) is particularly affected by increasing attentional load.

The deterioration that Baldisserri et al. (2014) observed in their drivers’ performance could have been caused by either a change in their coordination patterns for steering (i.e., destabilization), a change in their visual attention, or both (i.e., covariation) (Monno, Temprado, Zanone, & Laurent, 2002). Previous work has shown that following another car causes drivers to reallocate visual attention to a narrower visual-search strategy in which they pay significantly more attention to the car ahead compared to the wider visual-search used when following route directions (Crundall, Shenton, & Underwood, 2004). A narrower visual search strategy could increase a driver’s risk of making errors in perceiving key landmarks at the edge of the track. In normal driving, which was the subject of the study by Crundall et al. (2004), steering angle is tightly coupled to gaze direction (Land & Lee, 1994). In contrast, steering angle in formula car racing is more tightly coupled to head rotation than eye movement (Land & Tatler, 2001). Consequently, if formula car drivers reallocate their visual attention to a narrower visual-search strategy, it is likely to result in a change in their coordination pattern for head movement. Previous case studies have shown that a change in visual information affected the neck muscle activation patterns of a skilled amateur formula car driver when driving on a clear track (Rosalie & Malone, 2018a) and when following another car (Rosalie & Malone, 2018b). The authors reported that the change in neck muscle activation patterns was consistent with a change in head movement from rotation to lateral flexion. Lateral flexion of the head results in misperception of both objects in the environment (De Vrijer, Medendorp, & Van Gisbergen, 2009; Luyat, Gentaz, Corte, & Guerraz, 2001; Young, Oman, & Dichgans, 1975) and the orientation of one’s own head (Barnett-Cowan & Harris, 2008) due to E-effect, a tilt overcompensation caused by an increased sensitivity to roll stimuli (De Vrijer et al., 2009; Young et al., 1975). Tilting the head when following another car will induce a reorientation between the subjective visual vertical and the physical vertical and cause changes in perception of differential motion parallax that are likely to affect drivers’ perception of relative distance (De Vrijer et al., 2009; Rogers &

Graham, 1979). This will reduce their ability to accurately locate key visual cues such as the tangent point of a corner or the position of another vehicle (Cutting, Springer, Braren, & Johnson, 1992; Land & Tatler, 2001) thereby reducing the margin for error. Therefore, a change in head movement from rotation to lateral flexion could be considered a negative transfer of steering skill because it increases the risk of steering errors.

The tight coupling of a driver's head movement to steering angle (Land & Tatler, 2001), suggests that a change in the way drivers move their head is likely to influence the way they use their arms to turn the steering wheel. There are several studies that have examined the activity of various shoulder muscles thought to be involved in steering a road car (Jonsson & Jonsson, 1975a, 1975b, 1976; Pick & Cole, 2006). From these, it seems that anterior deltoid and pectoralis major are the prime movers of steering (Pick & Cole, 2006). Steering torque is provided by the ipsilateral pectoralis major and the contralateral anterior deltoid (Pick & Cole, 2006). So, turning right involves co-contraction of left anterior deltoid and right pectoralis major while turning left involves co-contraction of right anterior deltoid and left pectoralis major. However, all the current studies examining shoulder muscle activity during steering have been performed using a road car simulator rather than being performed on-the-road. The cockpit of an open-cockpit racing car travelling at more than 200 km/h is a very different environment to a laboratory-based road car simulator. Consequently, it is unclear whether shoulder muscle activation patterns measured in the laboratory are representative of what occurs on track. In addition, none of the current studies examining shoulder muscle activity during steering have considered the role of trunk muscles such as rectus abdominus, transversus abdominus and lumbar erector spinae in stabilizing the torso during movements of the arms. Activation of transversus abdominis in particular, is thought to be important in stabilizing the spine against shear and compressive forces associated with vertebral loading in rapid arm movements (Hodges, Cresswell, Daggfeldt, & Thorstensson, 2000; Hodges, Cresswell, & Thorstensson, 1999; Marshall & Murphy, 2003) and does so in a non-directional manner (Hodges & Richardson, 1997). In contrast, trunk extensors such as lumbar erector spinae activate in the opposite direction to the torque resulting from movements of the upper limb (Hodges et al., 2000; Hodges & Richardson, 1997). For example, right shoulder flexion is accompanied by activation of the left side back extensors. A stable posture is important in driving because a more stable posture improves visual performance (Stoffregen, Pagulayan, Bardy, & Hettinger, 2000) and is associated with expertise in driving (Treffner, Barrett, & Petersen, 2002). Therefore, it is important to measure the response of the trunk muscles to shoulder muscle activation during steering.

The aim of our experiment was to investigate whether the increased attentional demand of following another car closely caused a change in formula car drivers' coordination patterns for steering compared to driving on a clear track. Specifically, we sought to examine whether drivers transferred their muscle activation patterns for head movement, arm movement, and trunk stabilization when attentional demand was increased. Our first hypothesis was that formula car drivers will allocate attention to a narrower visual search strategy when they follow another car (see Crundall et al., 2004). We expect a narrowing of their visual search strategy will be accompanied by a reduction in their head movement. Consequently, the drivers' neck muscles will fatigue more slowly when they follow another car. Recognizing that formula car drivers' head movement is tightly coupled to their steering behavior (see Land & Tatler, 2001) leads to our second hypothesis. If drivers' head movement decreases when they follow another car, then their steering movements will also change. Consequently, the activation patterns of drivers' shoulder muscles will be different when they follow another car compared to when they drive on a clear track. If drivers' arm movements change, then so will the resultant torque in the spine. Consequently, a different pattern of trunk muscle activation will be required to stabilize the spine (see Hodges et al., 2000). Therefore, our third hypothesis was that following another car will cause a change in the activation patterns of drivers' trunk muscles compared to when they drive on a clear track.

Methods

Participants

Approval was granted by an institutional Human Research Ethics Committee to investigate the role of muscle activity in driver performance. Written informed consent to participate was obtained from four skilled amateur formula car drivers. Three drivers reported a mean age of 65 years (*SD* = 2) and mean motorsport experience of 29 years (*SD* = 23). Two drivers were currently competing at National Level, the highest level in their chosen Formula, and the third competed at club level. The fourth driver failed to complete an experience questionnaire.

Materials

All testing was conducted at a private racing track 4 km (2.5 mile) in length with a clockwise track configuration. Each lap included eleven right-hand corners and eight left-hand corners. For logistical reasons, the first two drivers were tested in the third week of July of year one and the second two in the same week of the following year.

All four drivers drove their own Formula Mazda, open-cockpit, open wheel, single-seater race car. The Formula Mazda is constructed on a tubular steel chassis and is powered by a 180 hp Mazda 13B rotary engine. Engines are sealed to ensure parity. Race weight with driver is 614kg which makes the Formula Mazda's performance close to that of Formula Renault 2.0 (185-210 hp/565kg with driver). All four cars were prepared and set up to Sports Car Club of America specifications by the same mechanic.

The drivers' muscle activation patterns were measured using wireless surface electromyography sensors with integrated inertial measurement units (Delsys, Trigno IM, Boston, MA, USA). The subset of data presented here are bilateral sEMG recordings from the drivers' sternocleidomastoid, cervical erector spinae, anterior deltoid, pectoralis major, lumbar erector spinae, rectus abdominus and transversus abdominus/iliopsoas. The measuring electrodes were positioned according to the recommendations of the Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles (SENIAM) Project for the placement of measuring electrodes (Hermens et al., 1999). The measuring electrode for pectoralis major was placed medially along the line of the sternal portion of pectoralis major to capture its activity during downward movements of the steering wheel (Król, Sobota, & Nawrat, 2007; Pick & Cole, 2006) and the electrode for transversus abdominus was placed according to the recommendations of Marshall and Murphy (2003). The data were recorded to the manufacturer supplied data logger in millivolts at a rate of 1111Hz. The sEMG data logger included a tri-axial accelerometer which sampled at 148Hz. Track position was measured using a 10 Hz global positioning system tracking unit with an integrated 100Hz inertial measurement unit (Catapult Optimeye S5, Catapult Sports, Docklands, Australia). The same global positioning system unit was used for every test. The data loggers were mounted together in the cockpit of the car.

Experimental Design and Testing Procedure

A within-subjects design was used to compare drivers' muscle activity between driving on a clear track (solo) and following another car (following). Each driver completed the solo driving task before the following task to mimic the pattern of a typical race meeting. The drivers' goal in the solo task was to set unimpeded lap-times. The track was closed to all other vehicles during testing. The driver's goal during the following task was to follow another car closely and position themselves to overtake it at each corner but remain behind throughout. For safety reasons, only the test driver and the lead vehicle were present on the track during following. Each task commenced in the pits where the mechanic prepared the driver as he usually would for practice, qualifying, or racing. The experimenter activated the data loggers, synchronized them using a sequence of taps, then cleared the driver(s) to leave the pits. Both tasks followed the same pattern: two warm-up laps, ten full-pace laps, and a cool-down lap. To orient the drivers to competitive driving, a green flag was used to signal the start of the full-pace laps and a checkered flag was used to signal the finish. Both tasks were run on the same day rather than on consecutive days for logistical reasons. So, the distance and duration of each session was made slightly shorter than a typical race distance (25-35 minutes/35-50 miles). After completing the solo task, the driver retired to an air-conditioned lounge to rest, rehydrate, and prepare for the intentional following task. The surface electromyography electrodes were left in place until the driver completed both tasks.

Data Processing and Statistical Analysis

Delsys EMGworks (Delsys, Boston, MA, USA) was used for initial data processing. This consisted of importing the positioning data and synchronizing it with the surface electromyography data based on the sequence of taps recorded by the Optimeye and Delsys data logger. The positioning data were then used to identify the timepoints in the surface electromyography record when the test driver crossed the start-finish line to commence the full-pace laps and when he crossed to complete them. A subset of the surface electromyography recordings from the start to the finish of the full-pace laps was created using these timepoints and extracted for further processing according to the method used by Rosalie and Malone (2018a, 2018b, 2019). First, we applied a 4th order Butterworth bandpass filter with corner frequencies of 20Hz and 500Hz. Then we calculated the median frequency of the power spectrum using a short-time Fourier transform with a moving window of 0.125s and a window overlap of 0.0625s. Finally, we Max-Min normalized the median frequency data with a range of 0-100 and time normalized from green flag (time=0) to checkered flag (time =1).

We used mixed effects growth models with maximum likelihood estimation to model individual change in normalized median frequency (NMF) over time. Our approach was to analyze muscle activity in three separate regions: the neck (sternocleidomastoid and cervical erector spinae), the shoulder girdle (anterior deltoid and pectoralis major), and the trunk (lumbar erector spinae, rectus abdominis and transversus abdominis). This approach recognizes that the activities of muscles controlling the movements of a joint (or set of joints) are linked. Time was nested within individual to create a series of two-level hierarchical models. The Level 1 model aggregates individual growth curves to estimate average initial NMF and the rate of change in NMF over time within drivers. The Level 1 model is an unconditional model because it does not include predictors. We progressively fitted separate linear, quadratic and cubic trends to the change in NMF over time in the neck, shoulder and trunk. The model with the best fit for each region was selected based on Chi-square likelihood ratio tests. The effect of individual differences was examined by progressively specifying random effects for intercept, slope, and both intercept and slope using a heterogenous first order autoregressive or a scaled identity structure. Again, the model with the best fit for each region was selected based on Chi-square likelihood ratio tests. This is the recommend strategy for exploring individual change in growth parameters over time (Field, 2013; Shek & Ma, 2011).

The Level 2, or conditional, model estimates the effect of predictors on interindividual variation in initial NMF and rate of change in NMF over time. A dummy variable was created as a predictor (i.e, task – solo vs. following). Driving solo was coded as 0 and following another car was coded as 1. The predictor was added to the Level 1 model with the best fit for each region to test whether driving task was predictive of drivers' initial NMF and different trajectory changes in NMF over time. Because we didn't model covariates that could affect initial NMF across drivers (e.g., cockpit ergonomics, hydration status, dominance), we focused on differences in rate of change. The linear trend for the rate of change in NMF was used to determine if driving task was predictive of muscle fatigue (i.e., muscle use) with fatigue shown by a negative slope (Cifrek, Medved, Tonković, & Ostojić, 2009; Phinyomark, Limsakul, Hu, Phukpattaranont, & Thongpanja, 2012; Rosalie & Malone, 2018a, 2018b). The quadratic trend was used to determine whether driving task was predictive of an acceleration or deceleration in the rate of fatigue over time. The cubic trend was used to determine whether the effect of any acceleration or deceleration in the rate of fatigue increased or diminished over time (Rosalie & Malone, 2018a; Shek & Ma, 2011). In accordance with recommendations, a quadratic trend was only specified (and reported) if driving task significantly predicted the linear trend. Likewise, the cubic trend was only specified (and reported) if task significantly predicted the quadratic trend (Field, 2013; Shek & Ma, 2011). We specified separate models for each muscle within each region. Similar data analytic strategies have been employed to examine shoulder muscle activity in patients treated for breast cancer (Oskrochi, Lesaffre, Oskrochi, & Shamley, 2016), neck muscle activity of an open-cockpit racing driver (Rosalie & Malone, 2018a, 2018b), the effect of cockpit ergonomics on neck and shoulder muscle activity (Rosalie & Malone, 2019), the effects of situational context on the real-world braking performance of motorcycle riders (Huertas-Leyva et al., 2019), and on the potential of motorcycle autonomous emergency braking to mitigate head injuries (Piantini et al., In press).

Results

Neck Muscle Activity

Following another car was associated with changes in the linear, quadratic, and cubic trends in the activation patterns of left sternocleidomastoid, right sternocleidomastoid and left cervical erector spinae ($ps < 0.001$), but not right cervical erector spinae ($p = 0.56$) (see Table 1). The linear trends for left sterno-cleidomastoid, right sternocleidomastoid, and left cervical erector spinae were significantly more positive when the drivers followed another car ($ps < 0.001$) indicating that all three muscles fatigued more slowly. Considering that drivers completed more right hand corners, the decrease in the rates of fatigue when following was more marked for right rotators (left sterno-cleidomastoid, $\beta = 21.88$) than right lateral flexors (right sternocleidomastoid, $\beta = 18.36$, right cervical erector spinae, $\beta = -1.80$) which suggests that head movement changed from axial rotation to lateral flexion, at least during right-hand corners. Still images taken from a camera mounted on the roll hoop behind the driver confirmed that the change in head movement also occurred during left-hand corners and revealed that it happened when the driver approached the rear of the car ahead on corner entry (Figure 1). The quadratic trends for left sternocleidomastoid, right sternocleidomastoid and left cervical erector spinae were significantly more negative in the following task ($ps < 0.001$) indicating that the rate of fatigue accelerated more in the following task. However, the significantly more positive cubic trends for left sternocleidomastoid, right sternocleidomastoid and left cervical erector spinae in the following task ($ps < 0.001$) revealed that the acceleration in the rate of fatigue diminished more rapidly in the following task.

Individual growth curves of each driver's neck muscle activity are shown in Figure 2. Rates of fatigue of left sternocleidomastoid, right sternocleidomastoid, left cervical erector spinae, and right cervical erector spinae did not vary across drivers ($ps > 0.05$). However, intercepts and slopes for left cervical erector spinae negatively and significantly covaried, cov (u_{0j} , u_{1j}) = - 0.63, $p = 0.041$ indicating that the more that drivers activated left cervical erector spinae at the beginning of the session, the faster it fatigued.

Shoulder Muscle Activity

Two drivers' data for left and right anterior deltoid could not be recovered due to equipment failure. Following another car was associated with changes in the linear and quadratic trends in the activation patterns of left anterior deltoid ($p < 0.001$, $p = 0.002$, respectively), left pectoralis major ($ps < 0.001$), right anterior deltoid ($p = 0.021$, $p = 0.018$, respectively), and right pectoralis major ($p < 0.001$, $p = 0.001$, respectively) (see Table 2). The linear trends for both anterior deltoids were significantly negative in the following task indicating that both muscles fatigued more rapidly compared to practice. In contrast, the linear trends for both pectoralis majors were significantly positive in the following task indicating that both muscles fatigued more slowly in the following task. The quadratic trends for both anterior deltoids were significantly positive in the following task indicating that the rates of fatigue for both muscles decelerated more in the following task. However, the quadratic trends for both pectoralis majors were significantly negative in the following task indicating that the rates of fatigue for both muscles accelerated more when following another car

Individual growth curves of each driver's shoulder muscle activity are shown in Figure 3. There was significant individual variation across time for left pectoralis major, var(u_{0j+1j}) = 8.37, $p < 0.001$ $p = 0.046$ and right pectoralis major, var(u_{0j+1j}) = 1.73, $p < 0.001$, $p = 0.049$, but not left anterior deltoid ($p = 0.16$) or right anterior deltoid ($p = 0.16$).

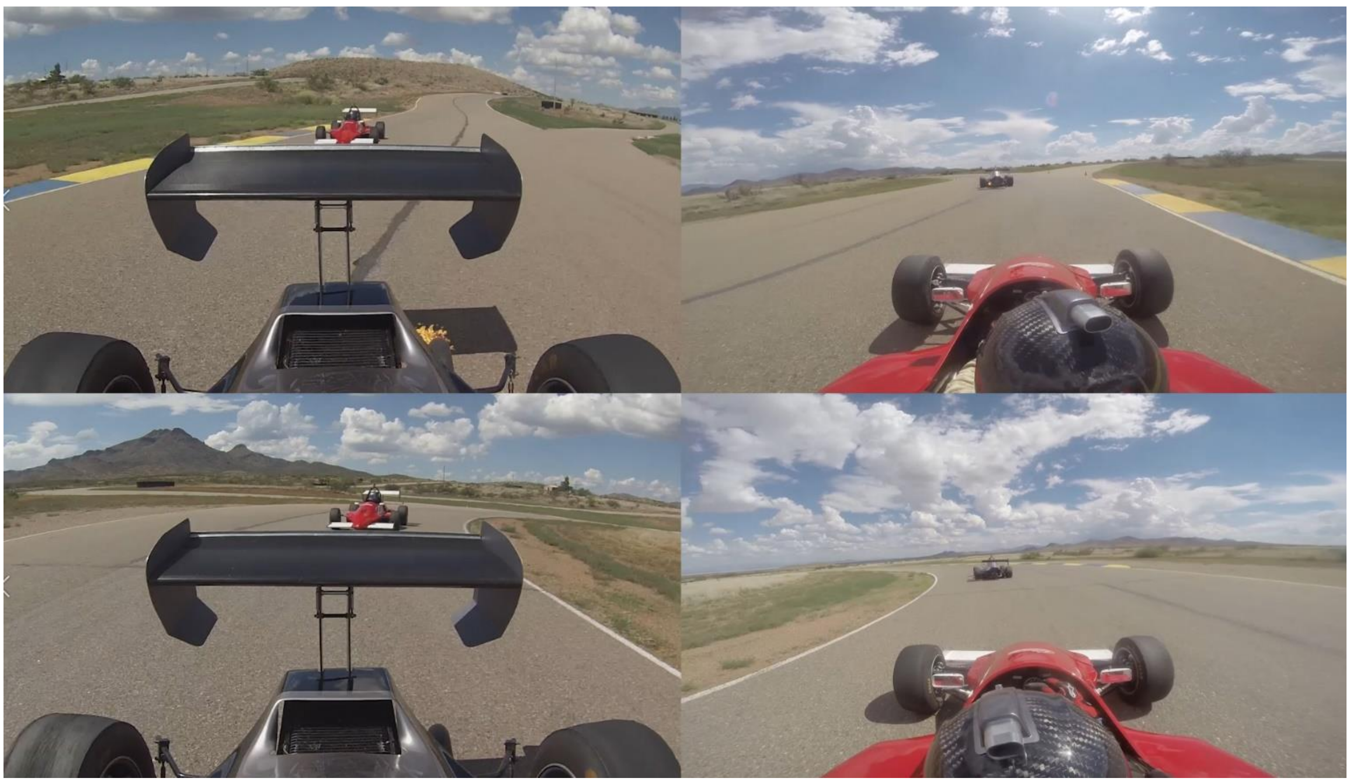

Figure 1. Still images from vehicle mounted video showing the rearward view (left) from the lead car and the forward view from the test driver's car (right). In the top row the test driver rotates his head to look at the corner apex. The bottom shows that, as he approaches the lead vehicle under brakes, his head position changes to lateral flexion

Table 1. Parameter estimates for the fixed and random effects of racing on NMF of left sternocleidomastoid (LSCM), right sternocleidomastoid (RSCM), left cervical erector spinae (LCES) and right cervical erector spinae (RCES).

Fixed effects

Muscle	Parameter	β	SE β	*df*	*t*	*p*	95% CI Lower	95% CI Upper
LSCM	Time	-20.81	2.38	46.50	-8.75	<0.001	-25.59	-16.02
	$Time^2$	26.39	4.66	107363.98	5.67	<0.001	17.26	35.51
	$Time^3$	-10.52	3.06	107363.98	-3.44	0.001	-16.52	-4.52
	Time x Task	21.88	2.81	107363.99	7.79	<0.001	16.38	27.38
	$Time^2$ x Task	-38.41	6.52	107363.98	-5.89	<0.001	-51.20	-25.62
	$Time^3$ x Task	21.31	4.29	107363.98	4.97	<0.001	12.91	29.72
RSCM	Time	-22.83	2.17	267.49	-10.53	<0.001	-27.10	-18.56
	$Time^2$	40.19	4.73	107363.89	8.49	<0.001	30.91	49.47
	$Time^3$	-22.23	3.11	107363.89	-7.14	<0.001	-28.33	-16.13
	Time x Task	18.36	2.85	107363.90	6.43	<0.001	12.77	23.95
	$Time^2$ x Task	-38.78	6.63	107363.89	-5.85	<0.001	-51.78	-25.79
	$Time^3$ x Task	22.71	4.36	107363.89	5.21	<0.001	14.16	31.25
LCES	Time	-36.40	2.32	396.71	-15.72	<0.001	-40.95	-31.85
	$Time^2$	71.15	5.12	107363.93	13.90	<0.001	61.11	81.18
	$Time^3$	-41.96	3.36	107363.93	-12.47	<0.001	-48.56	-35.37
	Time x Task	19.74	3.09	107363.94	6.40	<0.001	13.69	25.79
	$Time^2$ x Task	-41.38	7.17	107363.93	-5.77	<0.001	-55.44	-27.33
	$Time^3$ x Task	22.34	4.71	107363.93	4.74	<0.001	13.10	31.58
RCES	Time	-0.36	2.41	109.06	-0.15	0.881	-5.15	4.42
	$Time^2$	-0.97	5.06	107364.00	-0.19	0.848	-10.88	8.94
	$Time^3$	-0.40	3.32	107364.00	-0.12	0.905	-6.91	6.12
	Time x Task	-1.80	3.05	107364.01	-0.59	0.556	-7.77	4.18
	$Time^2$ x Task	12.84	7.08	107364.00	1.81	0.070	-1.04	26.72
	$Time^3$ x Task	-10.03	4.66	107364.00	-2.15	0.031	-19.15	-0.90

Random effects

Muscle	Parameter	β	SE β	Wald Z	*p*	95% CI Lower	95% CI Upper
LSCM	Variance in intercepts	46.70	33.05	1.41	0.158	11.67	186.90
	Variance in slopes	6.52	4.69	1.39	0.164	1.60	26.66
	Covariance	-0.50	0.38	-1.31	0.190	-0.91	0.42
RSCM	Variance in intercepts	88.95	62.92	1.41	0.157	22.24	355.82
	Variance in slopes	2.19	1.62	1.35	0.177	0.51	9.36
	Covariance	0.56	0.35	1.57	0.116	-0.36	0.93
LCES	Variance in intercepts	6.08	4.33	1.41	0.160	1.51	24.51
	Variance in slopes	2.04	1.52	1.34	0.180	0.47	8.80
	Covariance	-0.63	0.31	-2.05	0.041	-0.94	0.26
RCES	Variance in intercepts	14.57	10.32	1.41	0.158	3.63	58.41
	Variance in slopes	4.36	3.15	1.38	0.167	1.06	18.00
	Covariance	-0.37	0.44	-0.85	0.397	-0.88	0.54

Note. "β" is the estimated effect size. "SE β" is the standard error of β. "*df*" are the degrees of freedom. "*t*" and "Wald *Z*" are the standardized test scores. "*p*" is the significance of standardized score. "95% CI" is the 95% confidence interval of β. "Time," "$Time^2$," and "$Time^3$" are the linear, quadratic, and cubic trend, respectively, in the solo task. "Time x Task," "$Time^2$ x Task," and "$Time^3$ x Task" are the effects of intentional following on each trend.

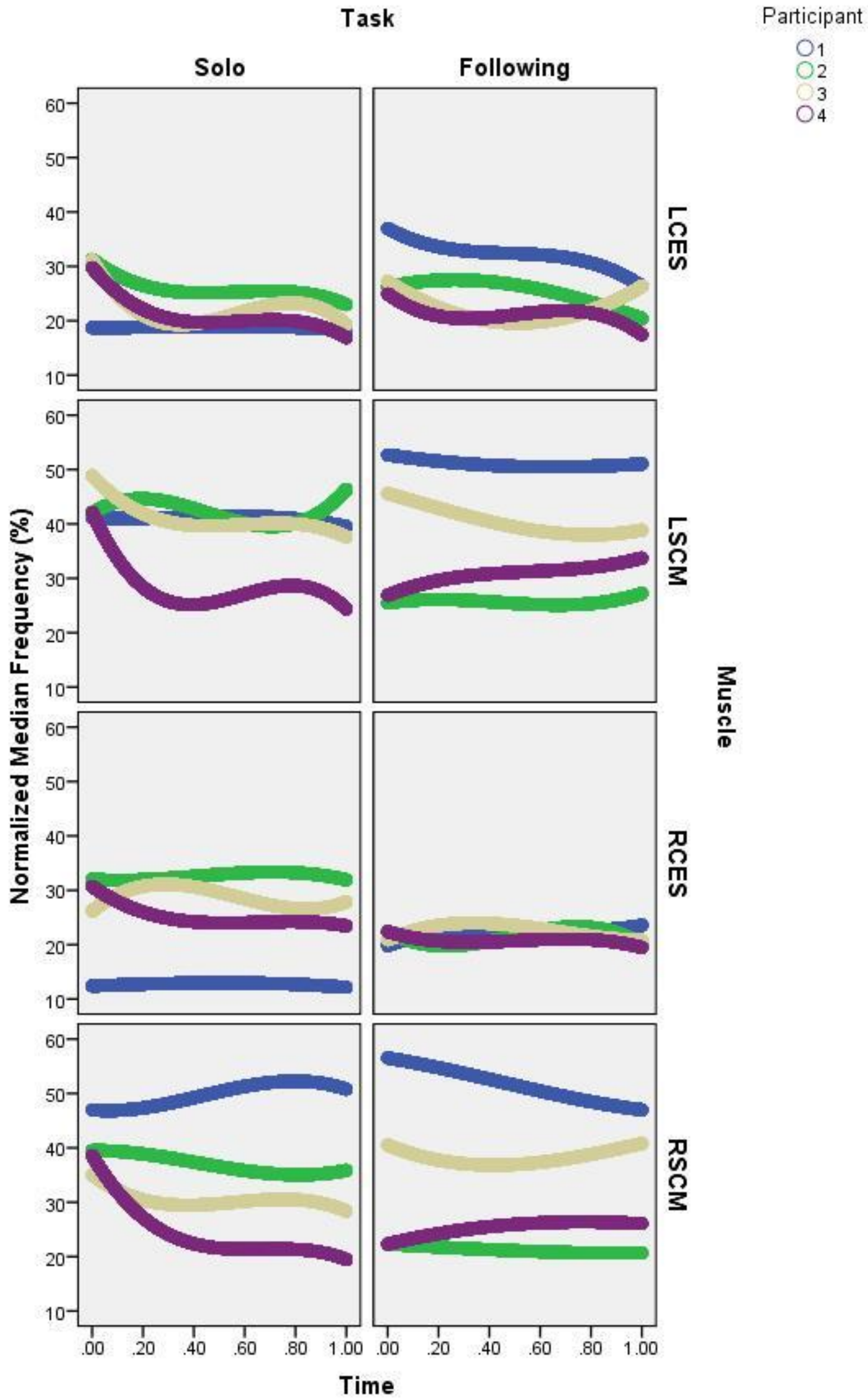

Figure 2. Individual growth curves for left cervical erector spinae (LCES), left sternocleidomastoid (LSCM), right cervical erector spinae (RCES), and right sternocleidomastoid (RSCM) showing the change in normalized median frequency over time in the solo task (left panels) and the following task (right panels)

Table 2. Parameter estimates for the fixed and random effects of racing on NMF of left anterior deltoid (LAD), right anterior deltoid (RAD), left pectoralis major (LPM), and right pectoralis major (RPM).

Fixed effects

Muscle	Parameter	β	SE β	*df*	*t*	*p*	95% CI Lower	95% CI Upper
LAD	Time	-8.70	2.91	5.42	-2.99	0.028	-16.02	-1.38
	$Time^2$	8.11	1.06	40643.01	7.63	<0.001	6.02	10.19
	Time x Task	-7.68	1.53	40643.01	-5.02	<0.001	-10.68	-4.69
	$Time^2$ x Task	4.67	1.48	40643.01	3.15	0.002	1.77	7.58
RAD	Time	-7.04	3.05	6.47	-2.30	0.058	-14.38	0.31
	$Time^2$	7.39	1.38	40642.99	5.34	<0.001	4.68	10.11
	Time x Task	-4.58	1.99	40642.99	-2.30	0.021	-8.49	-0.68
	$Time^2$ x Task	4.56	1.93	40642.99	2.36	0.018	0.78	8.34
LPM	Time	-8.67	1.64	13.13	-5.29	<0.001	-12.20	-5.13
	$Time^2$	8.98	0.75	107364.07	12.05	<0.001	7.52	10.45
	Time x Task	10.89	1.08	107364.08	10.10	<0.001	8.78	13.01
	$Time^2$ x Task	-11.68	1.04	107364.07	-11.18	<0.001	-13.72	-9.63
RPM	Time	-6.50	0.89	26.50	-7.26	<0.001	-8.34	-4.66
	$Time^2$	4.60	0.59	107364.03	7.84	<0.001	3.45	5.75
	Time x Task	5.43	0.85	107364.06	6.39	<0.001	3.76	7.09
	$Time^2$ x Task	-2.80	0.82	107364.03	-3.40	0.001	-4.41	-1.19

Random effects

Muscle	Parameter	β	SE β	Wald Z	*p*	95% CI Lower	95% CI Upper
LAD	Variance in intercepts + time	14.57	10.32	1.41	0.158	3.64	58.39
RAD	Variance in intercepts + time	14.58	10.38	1.41	0.160	3.61	58.82
LPM	Variance in intercepts + time	8.37	4.20	2.00	0.046	3.14	22.36
RPM	Variance in intercepts + time	1.73	0.88	1.97	0.049	0.64	4.69

Note. "β" is the estimated effect size. "SE β" is the standard error of β. "*df*" are the degrees of freedom. "*t*" and "Wald Z" are the standardized test scores. "*p*" is the significance of standardized score. "95% CI" is the 95% confidence interval of β. "Time," "$Time^2$," and "$Time^3$" are the linear, quadratic, and cubic trend, respectively, in the solo task. "Time x Task," "$Time^2$ x Task," and "$Time^3$ x Task" are the effects of intentional following on each trend.

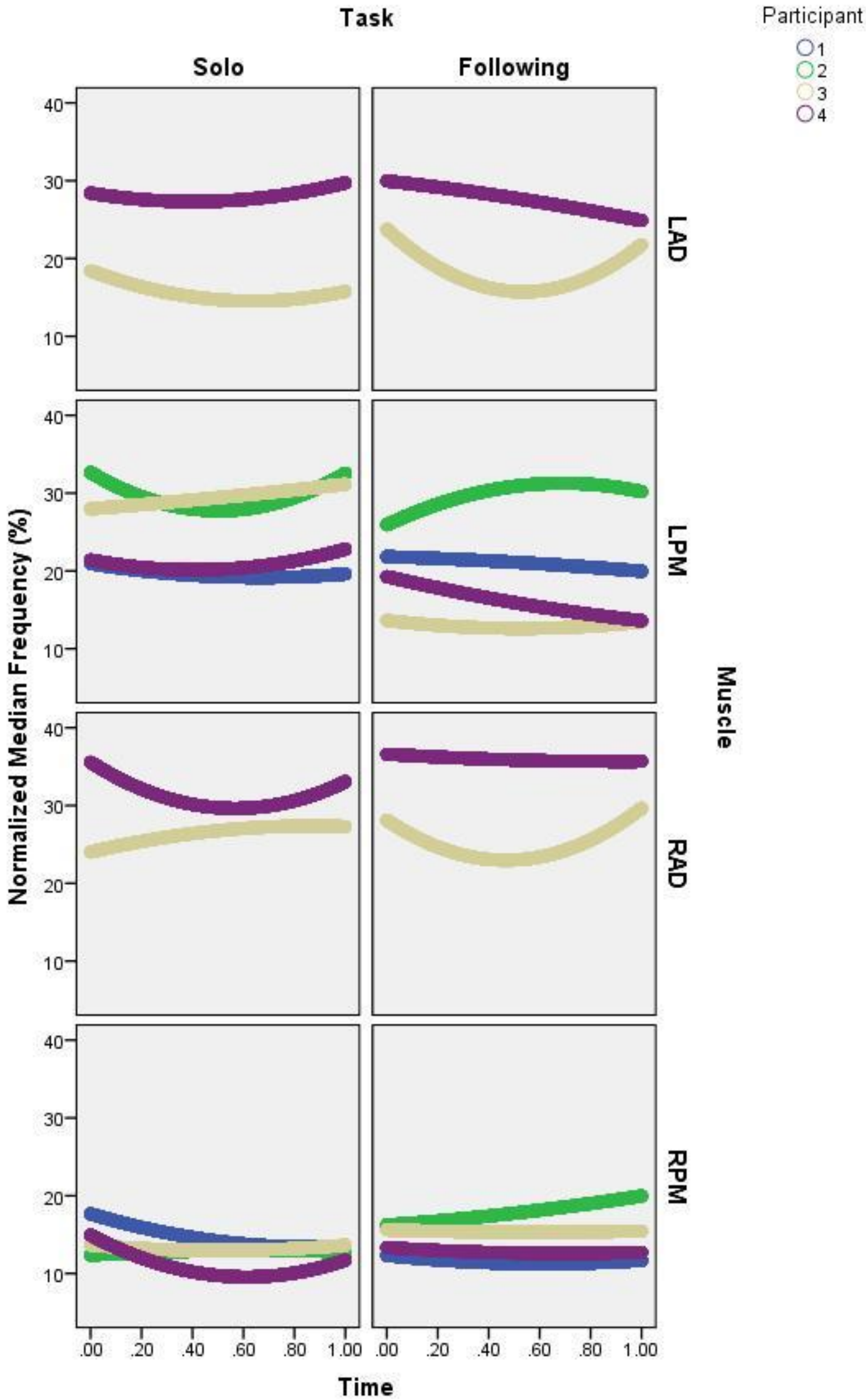

Figure 3. Individual growth curves for left anterior deltoid (LAD), left pectoralis major (LPM), right anterior deltoid (RAD), and right pectoralis major (RPM) showing the change in normalized median frequency over time in the solo task (left panels) and the following task (right panels).

Trunk Muscle Activity

Following another car was associated with changes in the linear trends in the activation patterns of left lumbar erector spinae, left rectus abdominis, left transversus abdominis, right rectus abdominis (*ps* < 0.001), and right transversus abdominis ($p = 0.014$), but task did not predict a change in right lumbar erector spinae ($p = 0.47$) (see Table 3). Following another car was also associated with changes in the quadratic trend in activation patterns of left lumbar erector spinae ($p = 0.001$), left rectus abdominis ($p < 0.001$), left transversus abdominis ($p < 0.001$), right rectus abdominis ($p < 0.001$), but not right transversus abdominis ($p = 0.55$). Lastly, following another car was also associated with changes in the cubic trend in the activation patterns of left rectus abdominis ($p < 0.001$), left transversus abdominis ($p < 0.001$), and right rectus abdominis ($p < 0.001$), but not left lumbar erector spinae ($p = 0.52$), or right transversus abdominis ($p = 0.55$). The linear trends for left lumbar erector spinae, left transversus abdominis, and right transversus abdominis were significantly more positive in the following task ($p < 0.001$, $p < 0.001$, $p = 0.014$, respectively). In contrast, the linear trends for left rectus abdominis and right rectus abdominis were significantly more negative in the following task (*ps* < 0.001). The effect sizes for left lumbar erector spinae ($\beta = 23.87$) and left transversus abdominis ($\beta = 42.98$) and right transversus abdominis ($\beta = 8.45$) suggests a decrease in muscle activation for stabilization of the spine against torque produced by movements of the upper limb; particularly, flexion of the right upper limb. In contrast, the effect sizes for left rectus abdominis ($\beta = -20.33$), right rectus abdominis ($\beta = -27.53$) suggest an increased need to stabilize the spine particularly on the right. The quadratic trends for left lumbar erector spinae and left transversus abdominis were significantly more negative in the following task (*ps* < 0.001) indicating that the rate of fatigue accelerated more in the following task. However, the quadratic trends for left rectus abdominis and right rectus abdominis were significantly more positive in the following task (*ps* < 0.001) indicating that the rate of fatigue accelerated more in the solo task. Lastly, the cubic trends for left rectus abdominis and right rectus abdominis was significantly more negative in the following task indicating that the acceleration in the rate of fatigue diminished more slowly in following task (*ps* < 0.001), while significantly more positive cubic trend for left transversus abdominis indicating that the acceleration in the rate of fatigue diminished more rapidly in following task ($p < 0.001$).

Individual growth curves of each driver's trunk muscle activity are shown in Figure 4. The activation patterns for left lumbar erector spinae, left rectus abdominis, left transversus abdominis, right lumbar erector spinae, right rectus abdominis or right transversus abdominis did not vary across drivers (*ps* > 0.05). However, intercepts and slopes for left lumbar erector spinae positively and significantly covaried, cov (u_{0j} , u_{1j}) = 0.96, $p < 0.001$ indicating the more drivers activated left lumbar erector spinae at the beginning of the session, the slower it fatigued. In contrast, intercepts and slopes for right lumbar erector spinae negatively and significantly covaried, cov (u_{0j} , u_{1j}) = -0.83, $p < 0.001$ indicating that as muscle use increased rate of fatigue increased.

Table 3. Parameter estimates for the fixed and random effects of racing on NMF of left and right lumbar erector spinae (LLES, RLES), left and right rectus abdominis (LRA, RRA), and left and right transversus abdominis (LTA, RTA).

		Fixed effects						
							95% CI	
Muscle	Parameter	β	SE β	*df*	*t*	*p*	Lower	Upper
LLES	Time	-12.43	3.13	13.29	-3.98	0.002	-19.17	-5.69
	$Time^2$	5.24	4.89	107363.90	1.07	0.285	-4.36	14.83
	$Time^3$	4.74	3.22	107363.90	1.47	0.141	-1.57	11.04
	Time x Task	23.87	2.95	107363.91	8.09	<0.001	18.09	29.65
	$Time^2$ x Task	-23.31	6.86	107363.90	-3.40	0.001	-36.74	-9.87
	$Time^3$ x Task	2.87	4.51	107363.90	0.64	0.524	-5.96	11.71
RLES	Time	-18.23	2.43	17.57	-7.51	<0.001	-23.33	-13.12
	$Time^2$	22.40	4.09	107363.98	5.48	<0.001	14.38	30.41
	$Time^3$	-8.06	2.69	107363.98	-3.00	0.003	-13.32	-2.79
	Time x Task	-1.78	2.46	107363.98	-0.72	0.470	-6.61	3.05
	$Time^2$ x Task	-11.75	5.73	107363.98	-2.05	0.040	-22.98	-0.53
	$Time^3$ x Task	10.84	3.76	107363.98	2.88	0.004	3.46	18.21
LRA	Time	-3.61	2.88	14.41	-1.25	0.230	-9.78	2.55
	$Time^2$	-2.88	4.62	107364.00	-0.62	0.534	-11.93	6.18
	$Time^3$	5.35	3.04	107364.00	1.76	0.078	-0.60	11.31
	Time x Task	-20.33	2.78	107364.00	-7.30	<0.001	-25.79	-14.87
	$Time^2$ x Task	46.57	6.47	107364.00	7.20	<0.001	33.88	59.25
	$Time^3$ x Task	-29.04	4.25	107364.00	-6.83	<0.001	-37.37	-20.70
RRA	Time	-9.52	4.58	7.43	-2.08	0.074	-20.23	1.19
	$Time^2$	3.28	5.51	107364.00	0.59	0.552	-7.52	14.07
	$Time^3$	2.50	3.62	107364.00	0.69	0.490	-4.59	9.60
	Time x Task	-27.53	3.32	107364.00	-8.29	<0.001	-34.04	-21.03
	$Time^2$ x Task	63.72	7.72	107364.00	8.26	<0.001	48.60	78.84
	$Time^3$ x Task	-41.95	5.07	107364.00	-8.27	<0.001	-51.89	-32.01
LTA	Time	-65.64	3.25	41.45	-20.18	<0.001	-72.21	-59.07
	$Time^2$	119.90	6.29	107364.00	19.06	<0.001	107.58	132.23
	$Time^3$	-62.85	4.13	107364.00	-15.20	<0.001	-70.95	-54.74
	Time x Task	42.98	3.79	107364.00	11.33	<0.001	35.54	50.41
	$Time^2$ x Task	-63.06	8.81	107364.00	-7.16	<0.001	-80.33	-45.79
	$Time^3$ x Task	29.25	5.79	107364.00	5.05	<0.001	17.89	40.60
RTA	Time	-7.59	2.73	105.48	-2.78	0.006	-13.01	-2.17
	$Time^2$	-6.05	5.71	107364.01	-1.06	0.289	-17.24	5.14
	$Time^3$	12.36	3.75	107364.01	3.29	0.001	5.00	19.71
	Time x Task	8.45	3.44	107364.02	2.45	0.014	1.70	15.19
	$Time^2$ x Task	4.82	8.00	107364.01	0.60	0.547	-10.86	20.49
	$Time^3$ x Task	-9.93	5.26	107364.01	-1.89	0.059	-20.23	0.38

Table 3., continued.

Random effects							
						95% CI	
Muscle	Parameter	β	SE β	Wald Z	*p*	Lower	Upper
LLES	Variance in intercepts	26.23	18.56	1.41	0.158	6.55	105.01
	Variance in slopes	21.39	15.18	1.41	0.159	5.32	85.96
	Covariance	0.96	0.04	22.71	<0.001	0.71	0.99
RLES	Variance in intercepts	27.40	19.39	1.41	0.158	6.85	109.67
	Variance in slopes	11.16	7.94	1.41	0.160	2.77	45.02
	Covariance	-0.83	0.16	-5.18	<0.001	-0.97	-0.19
LRA	Variance in intercepts	33.82	23.93	1.41	0.158	8.45	135.38
	Variance in slopes	17.44	12.39	1.41	0.159	4.33	70.18
	Covariance	0.04	0.50	0.08	0.934	-0.74	0.77
RRA	Variance in intercepts	66.90	47.34	1.41	0.158	16.72	267.73
	Variance in slopes	61.55	43.59	1.41	0.158	15.36	246.61
	Covariance	-0.44	0.40	-1.10	0.273	-0.90	0.47
LTA	Variance in intercepts	27.25	19.31	1.41	0.158	6.80	109.30
	Variance in slopes	12.99	9.29	1.40	0.162	3.20	52.78
	Covariance	-0.40	0.42	-0.94	0.349	-0.89	0.51
RTA	Variance in intercepts	26.36	18.67	1.41	0.158	6.58	105.61
	Variance in slopes	5.69	4.11	1.39	0.166	1.38	23.42
	Covariance	-0.08	0.50	-0.15	0.881	-0.79	0.72

Note. "β" is the estimated effect size. "SE β" is the standard error of β. "*df*" are the degrees of freedom. "*t*" and "Wald Z" are the standardized test scores. "*p*" is the significance of standardized score. "95% CI" is the 95% confidence interval of β. "Time," "$Time^2$,", and "$Time^{3}$" are the linear, quadratic. and cubic trend, respectively, in the solo task. "Time x Task," "$Time^2$ x Task," and "$Time^3$ x Task" are the effects of intentional following on each trend.

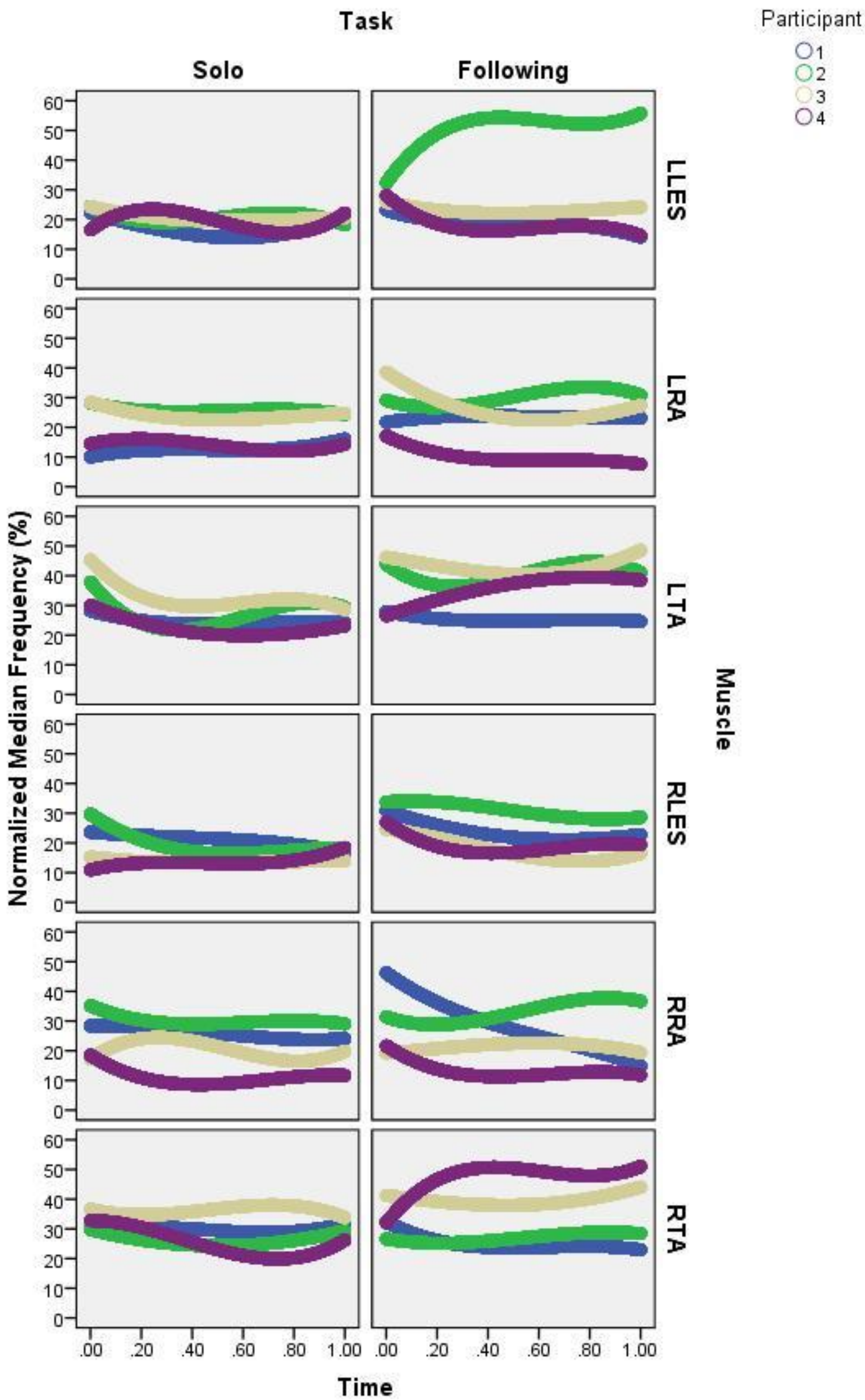

Figure 4. Individual growth curves for left lumbar erector spinae (LLES), left rectus abdominis (LRA), left transversus abdominis (LTA), right erector spinae (RLES), right rectus abdominis (RRA), and right transversus abdominis (RTA) showing the change in normalized median frequency over time in the solo task (left panels) and the following task (right panels).

Discussion

Our first hypothesis, that drivers will allocate attention to a narrower visual search strategy when they follow another car resulting in a decrease in the rate of fatigue of their neck muscles, was supported by the results. Rates of fatigue decreased in the muscles of the neck when drivers followed another car. This suggests that head movement decreased. We believe that this decrease in the drivers' head movement when following another car is symptomatic of a narrowing in their visual search strategy in a similar manner to what has previously been reported in simulated road driving (Crundall et al., 2004; Land & Tatler, 2001). It seems likely that when cornering the drivers shifted their attention away from the tangent point of the curve and towards the car ahead because this is when the majority of head movement occurs (Crundall et al., 2004; Land & Lee, 1994; Land & Tatler, 2001). The change in the movement pattern of the head from rotation to lateral flexion (see Figure 1) may represent a compensatory response. When faced with increased demands on spatial attention, people often use a physical action to reduce the demand, a process known as cognitive offloading (Risko & Gilbert, 2016). For example, externally normalizing the orientation of rotated text by tilting the head is less demanding on spatial attention and improves reading performance compared to internally normalizing the reference frame (Risko, Medimorec, Chisholm, & Kingstone, 2014). The drivers could have transferred this behavior by making voluntary movements of their heads to reduce the attentional demands of simultaneously perceiving the egocentric motion of their own vehicle relative to the track and the vehicle ahead as well as the allocentric motion of vehicle ahead relative to the track (see Wexler, 2003). In other words, the drivers may have attempted to normalize their perception of corner apexes by tilting their heads to look around the vehicle ahead. We have previously reported that a fixed visual obstruction positioned centrally just in front of the cockpit had a similar effect on a driver's head movement (Rosalie & Malone, 2018a, 2018b). However, lateral flexion of the head during cornering could result in drivers misperceiving the position and motion of the car ahead (De Vrijer et al., 2009; Luyat et al., 2001; Young et al., 1975) as well as the distance between cars (De Vrijer et al., 2009; Rogers & Graham, 1979) thereby increasing the risk of a vehicle-vehicle collision.

Our second finding was the production of steering torque in the following task shifted towards anterior deltoid and away from pectoralis major. The reason for this change is unclear although it may relate to the stabilization of the arm (Pick & Cole, 2006). One possible explanation is that the drivers utilized a less stable upper limb-steering wheel coordination structure to allow for more rapid changes in direction in response to the movement of the vehicle ahead. In addition, the shift in fatigue away from transversus abdomini and towards rectus abdomini may reflect the shift from stabilizing against negative tangential steering torque produced by pectoralis major towards positive tangential steering torque produced by anterior deltoid (Pick & Cole, 2006).

Our findings have implications with respect to transfer of learning in visual attention across the continuum of practice, qualifying, and racing in motorsport. Previous work suggests that the attentional cost of maintaining stable bimanual coordination dynamics decreases with practice (i.e., training) (Temprado, Monno, Zanone, & Kelso, 2002) and extensive practice is required to mitigate the detrimental effects that a dual-task condition has on task performance (Dux et al., 2009). When the constraints of practice require drivers to attend to one source of visual information (i.e., the track) they may be less able to transfer optimal steering behavior to the contexts that require them to attend to two (or more) sources such as racing (Newell, 1996; Rosalie & Müller, 2012). The implication is that despite being highly skilled, the drivers in our study have not deliberately practiced following another car sufficiently for the spatial representations of the two vehicles to be integrated into a unified temporal pattern, thereby creating a single task from a dual-task (Franz, Zelaznik, Swinnen, & Walter, 2001). This is likely to be a consequence of drivers using practice to optimize vehicle setup rather than to practice deliberately such key skills as overtaking. Using practice in this manner is typical of formulae with restricted practice, such as Formula 1. Research has shown that dual-task conditions negatively affect the driving performance of skilled formula car drivers in a high-fidelity simulator (Baldisserri et al., 2014). Therefore, we suggest that drivers incorporate deliberate practice of driving a racing car under dual-task conditions into their training regime, either in a simulator or on track, to improve their performance. Such practice should include the visual dual-task of intentional following to reduce drivers' risk of colliding with another vehicle.

The major limitation of this study is the sample size. It is important to recognize that we tested a small sample of older drivers with quite variable experience (*SD* = 23). The variability in the experience of the drivers may have contributed to the individual differences that we observed in the activation patterns of left cervical erector spinae, left and right pectoralis major, and left and right lumbar erector spinae. Although the effect sizes for the random and fixed effects suggests that individual differences had a smaller effect on patterns of muscle activation than the following task. The effect size for the following task could have also been influenced by the order that the drivers completed the tasks because the drivers all completed the solo task before the following task. Consequently, our results should be taken cautiously. Nonetheless, as far as we are aware ours is the first track-based study describing how different driving tasks affect the muscle activation patterns of a group of formula car drivers to be published in a peer-reviewed scientific journal. Previously, only single participant case studies of the perceptual-motor control processes of formula car drivers driving on-track have been reported in the scientific literature (e.g., Ferguson & Myers, 2018; Land & Tatler, 2001; Rosalie & Malone, 2018a, n = 1; 2018b; Rosalie & Malone, 2019). Walsh (2014) argued that useful generalizations can be made by studying even single elite athletes in the same manner that single patient case studies are used to inform neuropsychological practice. Nonetheless, the handful of studies reporting the physiological responses of a group of formula drivers measured on-track, such as ours and those by Ferguson, Barthel, Pruett, Buckingham, and Waaso (2019), Beaune and Durand (2011), Jacobs, Olvey, Johnson, and Cohn (2002) and Schwaberger (1987) are especially valuable because they provide insight into how individual drivers respond differently to the same stressors. The lack of published studies of formula car racing is undoubtably due in part to "secrecy" (Hoyes & Collins, 2018), but the resources, both financial and physical, required to test a formula car driver on the track should not be underestimated. In this study, we have generalized to the relatively small population of skilled formula car drivers based on a sample of four drivers tested in the natural setting. While our sample might be small, our modeling included more than 1.5 million data points. Studies of road driving behavior conducted in the natural setting have included single case studies with far fewer data points to which generalizations have been made to the much larger population of road drivers. Therefore, we believe that the sample size is sufficient given the methodology used in this experiment.

To our knowledge, this is the first study of the steering behavior of formula car drivers conducted in the natural setting to have included more than a single case. The key finding of our study was that skilled amateur formula car drivers change their patterns of neck, shoulder, and trunk muscle activation when they follow another car closely. In particular, the change in pattern of their neck muscle activity was consistent with the allocation of attention to a narrower visual search strategy compared to when they were not following another car. Our results suggest that despite their years of experience, the drivers that participated in our experiment had not sufficiently practiced following another car enough to transfer stable bimanual coordination dynamics for steering from a practice/qualifying task to a racing task.

Acknowledgements

The authors wish to acknowledge Raptor Motorsports for logistical support, Inde Motorsports Ranch for providing the track and associated track services, Arrow Karts and Yamaha Motor Australia for their support in providing go-karts which served as the initial test bed, and Thomas Sparkes who served as a test driver.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Authors' Declarations

James M. Malone is the president of Raptor Motorsports which provided funding for logistical support. The authors declare no further personal or financial conflicts of interest regarding the research in this article.

The authors declare that they conducted the research reported in this article in accordance with the Ethical Principles of the Journal of Expertise.

The authors declare that they are not able to make the dataset publicly available but are able to provide it upon request.

References

Baldisserri, L., Bonetti, R., Pon, F., Guidotti, L., Losi, M. G., Montanari, R., . . . Collina, S. (2014). Motorsport driver workload estimation in dual task scenario. Paper presented at the 6th International Conference on Advanced Cognitive Technologies and Applications. IARIA, Venice, Italy.

Barnett-Cowan, M., & Harris, L. R. (2008). Perceived self-orientation in allocentric and egocentric space: Effects of visual and physical tilt on saccadic and tactile measures. *Brain Research, 1242*, 231-243. doi:https://doi.org/10.1016/j.brainres.2008.07.075

Beaune, B., & Durand, S. (2011). Cardiac chronotropic adaptation to open-wheel racecar driving in young pilots. *International Journal of Performance Analysis in Sport, 11*(2), 325-334. doi:10.1080/24748668.2011.11868552

Cifrek, M., Medved, V., Tonković, S., & Ostojić, S. (2009). Surface EMG based muscle fatigue evaluation in biomechanics. *Clinical Biomechanics, 24*(4), 327-340. doi:http://dx.doi.org/10.1016/j.clinbiomech.2009.01.010

Crundall, D., Shenton, C., & Underwood, G. (2004). Eye movements during intentional car following. *Perception, 33*(8), 975-986.

Cutting, J. E., Springer, K., Braren, P. A., & Johnson, S. H. (1992). Wayfinding on foot from information in retinal, not optical, flow. *Journal of Experimental Psychology: General, 121*(1), 41-72.

De Vrijer, M., Medendorp, W. P., & Van Gisbergen, J. (2009). Accuracy-precision trade-off in visual orientation constancy. *Journal of Vision, 9*(2), 9-9.

Dux, P. E., Tombu, M. N., Harrison, S., Rogers, B. P., Tong, F., & Marois, R. (2009). Training improves multitasking performance by increasing the speed of information processing in human prefrontal cortex. *Neuron, 63*(1), 127-138.

Ferguson, D., Barthel, S., Pruett, M., Buckingham, T., & Waaso, P. (2019). Physiological responses of male and female race car drivers during competition. *Medicine and Science in Sports and Exercise*. doi: 10.1249/MSS.0000000000001997

Ferguson, D. P., & Myers, N. D. (2018). Physical fitness and blood glucose influence performance in IndyCar racing. *The Journal of Strength & Conditioning Research, 32*(11), 3193-3206.

Field, A. (2013). *Discovering statistics using IBM SPSS statistics*: Sage Publications.

Franz, E. A., Zelaznik, H. N., Swinnen, S., & Walter, C. (2001). Spatial conceptual influences on the coordination of bimanual actions: When a dual task becomes a single task. *Journal of Motor Behavior, 33*(1), 103-112. doi:10.1080/00222890109601906

Hermens, H. J., Freriks, B., Merletti, R., Stegeman, D., Blok, J., Rau, G., . . . Hägg, G. (1999). European recommendations for surface electromyography. *Roessingh Research and Development, 8*(2), 13-54.

Hodges, P., Cresswell, A., Daggfeldt, K., & Thorstensson, A. (2000). Three dimensional preparatory trunk motion precedes asymmetrical upper limb movement. *Gait and Posture, 11*(2), 92-101.

Hodges, P., Cresswell, A., & Thorstensson, A. (1999). Preparatory trunk motion accompanies rapid upper limb movement. *Experimental Brain Research, 124*(1), 69-79.

Hodges, P., & Richardson, C. (1997). Feedforward contraction of transversus abdominis is not influenced by the direction of arm movement. *Experimental Brain Research, 114*(2), 362-370.

Hoyes, K., & Collins, D. (2018). Fit to race: Identifying the balance, type and sources of knowledge in fitness for Motorsport. *International Journal of Sports Science & Coaching, 13*(5), 751-760.

Huertas-Leyva, P., Nugent, M., Savino, G., Pierini, M., Baldanzini, N., & Rosalie, S. (2019). Emergency braking performance of motorcycle riders: Skill identification in a real-life perception-action task designed for training purposes. *Transportation research part F: traffic psychology and behaviour, 63*, 93-107. doi:https://doi.org/10.1016/j.trf.2019.03.019

Jacobs, C. (2019). Watch a blindfolded Alexander Rossi complete a lap of the Long Beach street circuit by memory. Retrieved from https://www.thedrive.com/accelerator/27822/watch-a-blindfolded-alexander-rossi-complete-a-lap-of-the-long-beach-street-circuit-by-memory

Jacobs, P. L., Olvey, S. E., Johnson, B. M., & Cohn, K. (2002). Physiological responses to high-speed, open-wheel racecar driving. *Medicine and Science in Sports and Exercise, 34*(12), 2085-2090. doi:10.1249/01.MSS.0000039307.03564.3D

Jonsson, S., & Jonsson, B. (1975a). Function of the muscles of the upper limb in car driving. *Ergonomics, 18*(4), 375-388.

Jonsson, S., & Jonsson, B. (1975b). Function of the muscles of the upper limb in car driving IV: The pectoralis major, serratus anterior and latissimus dorsi muscles. *Ergonomics, 18*(6), 643-649.

Jonsson, S., & Jonsson, B. (1976). Function of the muscles of the upper limb in car driving v: The supraspinatus, infraspinatus, teres minor and teres major muscles. *Ergonomics*, *19*(6), 711-717.

Król, H., Sobota, G., & Nawrat, A. (2007). Effect of electrode position on EMG recording in pectoralis major. *Journal of Human Kinetics, 17*, 105.

Land, M. F., & Lee, D. N. (1994). Where we look when we steer. *Nature, 369*(6483), 742-744. http://dx.doi.org/10.1038/369742a0

Land, M. F., & Tatler, B. W. (2001). Steering with the head: The visual strategy of a racing driver. *Current Biology, 11*, 1215-1220.

Luyat, M., Gentaz, E., Corte, T. R., & Guerraz, M. (2001). Reference frames and haptic perception of orientation: Body and head tilt effects on the oblique effect. *Perception and Psychophysics, 63*(3), 541-554. doi:10.3758/bf03194419

Marshall, P., & Murphy, B. (2003). The validity and reliability of surface EMG to assess the neuromuscular response of the abdominal muscles to rapid limb movement. *Journal of Electromyography and Kinesiology, 13*(5), 477-489. doi:10.1016/s1050-6411(03)00027-0

Monno, A., Temprado, J.-J., Zanone, P.-G., & Laurent, M. (2002). The interplay of attention and bimanual coordination dynamics. *Acta Psychologica, 110*(2), 187-211. doi:https://doi.org/10.1016/S0001-6918(02)00033-1

Müller, S., & Rosalie, S. M. (2019). Transfer of expert visual-perceptual-motor skill in sport. In A. M. Williams & R. C. Jackson (Eds.), *Anticipation and decision making in sport*: Routledge.

Newbon, J., Sims-Williams, D., & Dominy, R. (2017). Aerodynamic analysis of Grand Prix cars operating in wake flows. *SAE International Journal of Passenger Cars. Mechanical systems., 10*(1), 318-329.

Newell, K. M. (1996). Change in movement and skill: Learning, retention, and transfer. *Dexterity and its development*, 393-429.

Oskrochi, G., Lesaffre, E., Oskrochi, Y., & Shamley, D. (2016). An application of the multivariate linear mixed model to the analysis of shoulder complexity in breast cancer patients. *International Journal of Environmental Research and Public Health, 13*(3), 274-287.

Phinyomark, A., Limsakul, C., Hu, H., Phukpattaranont, P., & Thongpanja, S. (2012). The usefulness of mean and median frequencies in electromyography analysis. In Ganish R. Naik (Ed.) *Computational intelligence in electromyography analysis: A perspective on current applications and future challenges* (pp. 195-220): INTECH Open Access Publisher.

Piantini, S., Bourdet, N., Savino, G., Rosalie, S., Pierini, M., Deck, C., & Willinger, R. Potential head injury mitigation of M-AEB in real-world motorcycle crashes. *International Journal of Crashworthiness*. doi: 10.1080/13588265.2019.1626531

Pick, A. J., & Cole, D. J. (2006). Measurement of driver steering torque using electromyography. *Journal of Dynamic Systems, Measurement, and Control, 128*(4), 960-968.
Risko, E. F., & Gilbert, S. J. (2016). Cognitive offloading. *Trends in Cognitive Sciences, 20*(9), 676-688.
Risko, E. F., Medimorec, S., Chisholm, J., & Kingstone, A. (2014). Rotating With rotated text: A natural behavior approach to investigating cognitive offloading. *Cognitive Science, 38*(3), 537-564. doi:10.1111/cogs.12087
Rogers, B., & Graham, M. (1979). Motion parallax as an independent cue for depth perception. *Perception, 8*(2), 125-134.
Rosalie, S. M., & Malone, J. M. (2018a). The effect of a Halo-type structure on neck muscle activation of an open-cockpit race car driver training under qualifying conditions *BMJ Case Reports*. doi:10.1136/bcr-2017-224013
Rosalie, S. M., & Malone, J. M. (2018b). Effect of halo-type frontal cockpit protection on overtaking. *BMJ Case Reports, 2018*. doi:10.1136/bcr-2018-225427
Rosalie, S. M., & Malone, J. M. (2019). Women in motorsport: A case report of driving posture and performance after double mastectomy. *Physical Therapy in Sport 36*, 1-4. doi:https://doi.org/10.1016/j.ptsp.2018.12.005
Rosalie, S. M., & Müller, S. (2012). A model for the transfer of perceptual-motor skill learning in human behaviors. *Research Quarterly for Exercise and Sport, 83*(3), 413-421.
Rosalie, S. M., & Müller, S. (2014). Expertise facilitates the transfer of anticipation skill across domains. *The Quarterly Journal of Experimental Psychology, 67*(2), 319-334. doi:10.1080/17470218.2013.807856
Schwaberger, G. (1987). Heart rate, metabolic and hormonal responses to maximal psycho-emotional and physical stress in motor car racing drivers. *International Archives of Occupational and Environmental Health, 59*(6), 579-604.
Seifert, L., Boulanger, J., Orth, D., & Davids, K. (2015). Environmental design shapes perceptual-motor exploration, learning, and transfer in climbing. *Frontiers in Psychology, 6*, 1819.
Shek, D. T. L., & Ma, C. (2011). Longitudinal data analyses using linear mixed models in SPSS: concepts, procedures and illustrations. *The Scientific World Journal, 11*, 42-76.
Stoffregen, T. A., Pagulayan, R. J., Bardy, B. G., & Hettinger, L. J. (2000). Modulating postural control to facilitate visual performance. *Human Movement Science, 19*(2), 203-220.
Temprado, J. J., Monno, A., Zanone, P., & Kelso, J. A. S. (2002). Attentional demands reflect learning-induced alterations of bimanual coordination dynamics. *European Journal of Neuroscience, 16*(7), 1390-1394.
Treffner, P., Barrett, R., & Petersen, A. (2002). Stability and skill in driving. *Human Movement Science, 21*(5-6), 749-784.
Walsh, V. (2014). Is sport the brain's biggest challenge? *Current Biology, 24*(18), R859-R860.
Wexler, M. (2003). Voluntary head movement and allocentric perception of space. *Psychological Science, 14*(4), 340-346.
Young, L., Oman, C., & Dichgans, J. (1975). Influence of head orientation on visually induced pitch and roll sensation. *Aviation, Space, and Environmental Medicine, 46*(3), 264-268.

Received: 11 June 2019
Revision received: 8 October 2019
Accepted: 10 October 2019