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## CASE REPORT

# Effect of a halo-type structure on neck muscle activation of an open-cockpit race car driver training under qualifying conditions

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**SUMMARY**

The Fédération Internationale de l'Automobile recently mandated the use of the halo frontal cockpit protection system to mitigate the risk of impact to the driver's head. Here we describe the effect of a halo-type structure on the neck muscle activity of one of the authors, who is a national-level amateur racing driver, during a full qualifying session. We found that the workload of sternocleidomastoid increased and the workload of cervical erector spinae decreased with the halo fitted which is indicative of a forward head position. Left sternocleidomastoid and right cervical erector spinae fatigued more rapidly; whereas, left cervical erector spinae fatigued more slowly. There was no change in the rate of fatigue of right sternocleidomastoid. In combination with a forward head position, this suggests an increase in lateral flexion during head rotation which may affect accuracy of navigation. Thus, drivers may need to be trained to adapt to the halo to mitigate the effects on head position and movement.

**BACKGROUND**

In 2015, the Formula 1 community was stunned by the death of Jules Bianchi following a catastrophic head injury suffered during the 2014 Japanese Grand Prix. Bianchi's death was the first resulting from a crash during a Formula 1 Grand Prix since the deaths of Ayrton Senna and Roland Ratzenberger at the 1994 San Marino Grand Prix. In the wake of Bianchi's death and several other serious incidents involving impact to or near-misses with the drivers' head, the Fédération Internationale de l'Automobile (FIA) recently mandated the use of the halo frontal cockpit protection system for the 2018 Formula 1 season (Presenting the facts behind Halo, press release, 2017). The intention of the halo is to mitigate the risk of injury to the driver from: car-to-car contact, car-to-environment contact and external objects (F1- Why the Halo is the best solution, press release, 2017). Extensive modelling conducted by the FIA of previous open-cockpit race car accidents involving contact with the drivers' head suggests that the halo would have been effective in preventing or reducing injury (Presenting the facts behind Halo, press release, 2017). Despite the potential for the halo to improve driver safety, its introduction has been met with resistance. Among the concerns which have been raised, is the potential for drivers' vision to be adversely affected.

Feedback provided by the drivers following track tests performed during the second half of the 2016 Formula 1 season indicated that the halo did not adversely affect visibility (Presenting the facts behind Halo, press release, 2017). However, comments in the media suggest that the drivers' opinion remains divided.<sup>1</sup> To complicate the issue further, drivers are unable to verbally report the effect of the halo on non-conscious processes. Critically, both the accurate representation of spatial structure for the purposes of navigation and the avoidance of obstacles are controlled non-consciously by information from the peripheral visual system.<sup>2-6</sup> Because steering control is intimately linked to the driver's head movements,<sup>7</sup> if the halo influences a driver's head posture, this could affect their vehicle navigation and collision avoidance. Moreover, head postures closer to end range of motion, in combination with high levels of neck muscle activation, have been suggested to influence the pathomechanics of neck injury in high-g environments.<sup>8</sup>

Here we report a unique case of the effect of a 'halo-type' structure on the activation pattern of one driver's neck muscles during his initial exposure in the context of training. As a part of our continuous driver skill training programme, we perform an annual assessment of neck muscle function using electromyography (EMG). The data are used to plan each driver's skills training programme for the upcoming racing season. To ensure that the assessments model the constraints of the upcoming season, the vehicle is set up in accordance with any upcoming modification to the technical specifications which might reasonably impact on the drivers' skills programme. Because the FIA has stated that they intend to mandate the halo for all FIA open-cockpit championships (Presenting the facts behind Halo, press release, 2017), simulations were run using a Formula Mazda, a lower level open-cockpit race car, both with and without a 'halo-type' structure fitted to the cockpit to guide the driver's neck training programme. The purpose of the halo-type structure was to provide a training stimulus to prepare the driver for the potential impact of the central pillar on vehicle navigation.

**CASE PRESENTATION**

The driver, who is one of the authors, was a 70-year-old man with more than 10 years'



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**Figure 1** Driver's head position during the simulation with the halo-type structure fitted showing right lateral flexion on approach to a right-hand corner.

experience racing open-cockpit (Formula) cars at national level. The halo-type structure was custom fabricated on-site from circular steel tube with an outside diameter of 16.7 mm. This diameter was chosen to resemble the predicted diameter of the final design specification for the Formula 1 halo as closely as possible (Presenting the facts behind Halo, press release, 2017). The main hoop of the halo-type structure was mounted to the vehicle's main roll bar located directly behind the cockpit. It extended forwards 812 mm to the central pillar which was mounted to the front roll bar. The central pillar was swept back at an angle of 53°. The triangle at the intersection of the main hoop and the central pillar had a width of 113 mm at the top tapering to 17 mm at the base and a side length of 128 mm. The halo-type structure used was a mock-up intended to provide a training stimulus. The dimensions of the FIA homologated halo are only available to manufacturers.<sup>9</sup> Moreover, each team is permitted to modify non-structural elements of the halo to improve aerodynamic performance (Presenting the facts behind Halo, press release, 2017). Consequently, each halo is essentially unique. Indeed, it may even change from race to race as the teams update their aerodynamic package. This makes it problematic

to be completely faithful in producing a 'training halo'. As the training scenario reported here focused on the central pillar, the dimensions selected were midway between the dimensions of the central pillar of the prototype as published at the time of training (20 mm diameter) and the projected minimum diameter (12 mm) (Presenting the facts behind Halo, press release, 2017). The driver provided informed written consent for the publication of his training data as a case study.

## INVESTIGATIONS

Testing was conducted at Inde Motorsports Ranch, on a private race track 4 km in length with 11 right-hand and 8 left-hand corners. The race car used was a race-prepared Formula Mazda fitted with a 10 Hz Global Positioning System (GPS) tracking unit (Catapult Optimeye S5; Catapult Sports, Docklands, Australia) to obtain lap times and track position.

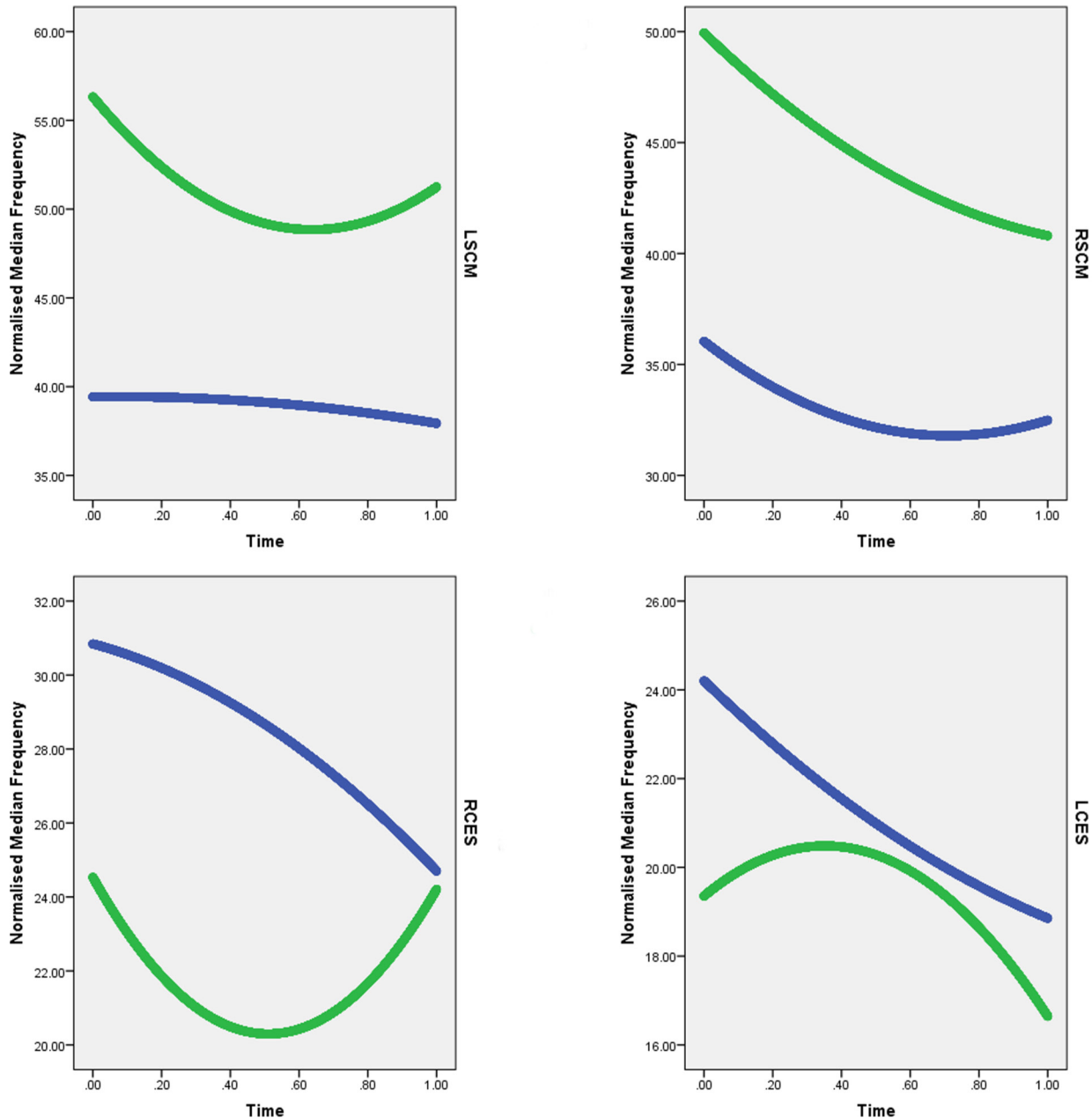
The driver was fitted with wireless surface EMG sensors (Delsys; Trigno IM, Boston, Massachusetts, USA) on the left sternocleidomastoid (LSCM) and right sternocleidomastoid (RSCM) and the left cervical erector spinae (LCES) and right cervical erector spinae (RCES). These sites were chosen because they allow for assessment of muscles involved in the movement of the head in all three cardinal planes without impinging on the normal position of the driver's helmet, which met the FIA 8860 standard, and Head and Neck Support (HANS) device (see figure 1). Data were recorded on a data logger mounted with the GPS tracking unit in the race car. Sensors were sited in accordance with the recommendations of the project (Surface Electromyography for the Non-Invasive Assessment of Muscles) for the placement of measuring electrodes.<sup>10</sup> Muscle activity was recorded in millivolts at a rate of 1111 Hz. The sensor sites were marked with indelible ink so that the sensors could be located identically across both driving sessions.

The driver completed qualifying simulations with and without the halo. Each simulation commenced in the pits. The driver was strapped into his car, and then the EMG and GPS data loggers were activated and synchronised by a sequence of taps. The driver then exited the pits and commenced driving two warm-up laps followed by 10 'flying laps'. After the 10 flying laps, the driver completed a cooldown lap before returning to the pits. Each simulation lasted approximately 18 min in total. The track was cleared of other vehicles during both simulations.

**Table 1** Table of estimates of the fixed effect of the halo-type structure on muscle workload, linear rate of fatigue and the quadratic rate of fatigue

Muscle	Parameter	b	Error	df	t	p	95% CI	
							Lower	Upper
LSCM	Workload	16.91	0.35	36 948	47.84	0.001	16.21	17.60
	Linear fatigue	-23.74	1.63	36 948	-14.54	0.001	-26.94	-20.54
	Quadratic fatigue	20.14	1.58	36 948	12.74	0.001	17.05	23.24
LCES	Workload	-4.85	0.44	36 948	-11.14	0.001	-5.70	-4.00
	Linear fatigue	13.92	2.01	36 948	6.92	0.001	9.98	17.86
	Quadratic fatigue	-11.28	1.95	36 948	-5.80	0.001	-15.10	-7.47
RSCM	Workload	13.90	0.38	36 948	36.72	0.001	13.16	14.64
	Linear fatigue	-3.02	1.75	36 948	-1.73	0.084	-6.45	0.40
	Quadratic fatigue	-2.57	1.69	36 948	-1.52	0.129	-5.88	0.75
RCES	Workload	-6.31	0.36	36 948	-17.67	0.001	-7.01	-5.61
	Linear fatigue	-14.07	1.65	36 948	-8.53	0.001	-17.30	-10.83
	Quadratic fatigue	19.88	1.60	36 948	12.45	0.001	16.75	23.02

'b' is the estimate of the fixed effect. 'Error' is the SE. 't' is the t-statistic for the fixed effect. P value is the significance of the effect. '95% CI' is the 95% CI for the fixed effect. LCES, left cervical erector spinae; LSCM, left sternocleidomastoid; RCES, right cervical erector spinae; RSCM, right sternocleidomastoid.



**Figure 2** Conditional growth curves for LSCM (top left), RSCM (top right), LCES (bottom left) and RCES (bottom right) showing the change in NMF over time with the halo-type structure (green) and without the halo-type structure (blue). LCES, left cervical erector spinae; LSCM, left sternocleidomastoid; NMF, normalised median frequency; RCES, right cervical erector spinae; RSCM, right sternocleidomastoid.

Ambient temperature, relative humidity, wind speed and direction, atmospheric pressure and ultraviolet (UV) index at 5 min intervals were sourced from the KAZWILLC26 weather station located approximately 12.5 km Northeast of the race track

Analysis of the time-dependent median frequency of the EMG power spectrum was used to determine measures of muscle load and fatigue. Delsys EMGworks was used to process the raw EMG data. The raw EMG recordings from each session were trimmed based on the GPS lap-time data so that only the data from the 10 flying laps were analysed further. The trimmed EMG data were bandpass filtered with a fourth order Butterworth filter with corner frequencies of 20 Hz and 500 Hz. The median frequency of the power spectrum was calculated using a short-time Fourier transform with a window length of 0.125 s and a window overlap of 0.0625 s. Median frequency data were then

normalised to a percentage of the maximum median frequency per muscle per test and time normalised.

Linear growth models were used to compare normalised median frequency (NMF) across the two simulations. The y-intercept of the fitted growth curve, which corresponded to the initial NMF, was used as an index of workload at the beginning of qualifying before fatigue modified the EMG signal.<sup>11 12</sup> An increase in workload resulted in an increase in instantaneous NMF.<sup>13</sup> The slope of the fitted growth curve, which corresponded to the rate of decrease in NMF, was used as an index of muscle fatigue.<sup>11 12</sup> Fatigue resulted in a downward shift in NMF which was represented by a negative slope.<sup>11-13</sup>

The session without the halo-type structure fitted commenced at 09:44 hours. The session with the halo-type structure was completed 4 days later and commenced at 14:25 hours. The

environmental conditions were similar across sessions: mean ambient temperature, 32.21°C–31.07°C; mean relative humidity, 10.15%–10.0%; mean wind speed and direction, 4.14 km/hour westerly to 0.09 km/hour east–southeasterly; mean barometric pressure, 2977–2985 Pa and mean UV index, 4.92–6.

### OUTCOME AND FOLLOW-UP

The results of the linear growth model analysis are presented in [table 1](#) and the fitted growth curves are shown in [figure 2](#). The halo-type structure was associated with significant increases in the workloads of LSCM ( $p < 0.001$ ) and RSCM ( $p < 0.001$ ) and significant decreases in the workloads of LCES ( $p < 0.001$ ) and RCES ( $p < 0.001$ ). The halo-type structure was associated with significantly negative linear rates of change for LSCM ( $p < 0.001$ ) and RCES ( $p < 0.001$ ) which suggests that both LSCM and RCES fatigued faster with the halo-type structure fitted. However, the quadratic rates of change were significantly positive for LSCM ( $p < 0.001$ ) and RCES ( $p < 0.001$ ) indicating that the rate of fatigue declined more rapidly with the halo-type structure fitted. In LCES, the halo-type structure was associated with a significantly positive linear rate of change ( $p < 0.001$ ) and significantly negative quadratic rate of change ( $p < 0.001$ ) indicating that LCES fatigued more slowly with the halo-type structure fitted but that the rate of fatigue increased more rapidly. In contrast, there was no significant difference in either the linear or quadratic rates of change of RSCM which suggested that the RSCM fatigued in a similar manner with and without the halo-type structure fitted.

### DISCUSSION

The increase in the workloads of LSCM and RSCM, and the concomitant decrease in the workloads of LCES and RCES suggests that the position of the driver's head is affected by fitment of the halo-type structure. One possible explanation for the change in the workload pattern of the muscles of the neck is that the driver adopts a forward head position when the halo-type structure is fitted. A forward head position is associated with an increase in EMG activity in the neck muscles,<sup>14</sup> and an increase in compressive loading on the cervical spine.<sup>15</sup> Although the available data are by no means complete, what is available suggests that a forward, or flexed, head posture has the potential to be problematic in the setting of open-cockpit racing. Preflexion of the cervical spine increases the incidence of compression and burst fractures in the lower cervical spine compared with a neutral spine.<sup>16</sup> Further evidence that increased cervical flexion is associated with spinal fracture risk can be found in comparisons of open-cockpit and closed-cockpit racing. In open-cockpit racing, the sharply reclined seating posture which induces cervical flexion results in an increased prevalence of spinal fractures in comparison with closed-cockpit racing in which drivers are seated in a more neutral posture.<sup>16</sup> Although it has been reported that head motion is not a contributing factor in cervical fractures sustained during a collision,<sup>16</sup> the ability to stabilise the head and neck in high-g environments is nonetheless critical. In a flexed head position, the neck muscles have reduced force-generating capacity<sup>17</sup> and mechanical advantage<sup>18</sup> compared with a neutral head position. Consequently, the ability to stabilise the head and neck is reduced. Studies of fighter pilots have shown that neck injury is associated with flexed neck position, particularly beyond 15°.<sup>19</sup> Forward head postures have also been associated with an increase in whiplash-associated disorders following automobile accidents involving rear-impact and side-impact collisions.<sup>20</sup>

### Patient's perspective

#### HALO Test week 2017

Modified halo device (16 mm with triangle splitter in front) fitted to 1990s Formula Mazda and constructed using photos of halo devices fitted on F1 cars available on the internet. Two separate tests were run: race simulation [Author's note: not reported here, analysis pending] with a leading car (another Formula Mazda) and running both clockwise and counter-clockwise; and single car qualifying with the same lapping format. Driver has thousands of miles at track and has years of experience in the formula car.

Entry and exit are a bit more difficult, but are easier with practice. However, in our design, no driver was able to enter between the car and the halo but rather had to climb 'over the top' for both entry and exit.

Initially when sitting in the car, the centre post caused 'double vision' and noticeable difficulty with depth perception. The impact of that double vision was lessened by looking at either side of the post. By focusing beyond the post, vision is clear but the post is still very distracting.

#### Qualifying simulation

The centre post was not much of an issue; however, there are plenty of photos showing head tilt (which was not a conscious decision) even on the straights. My lap times improved each lap and finally reached times that were very close to my best times.

#### Driver conclusions

1. We raced for 30 min, our usual class race, and my increased mental fatigue was noticeable. I am not an F1 driver. I was not in an F1 car fitted with a halo and my closing speeds were only 120–140 mph, but these vision issues would, in my opinion, cause significant brain fatigue over a 2-hour race, especially when closing speeds can approximate 200 mph.
2. The rapid loss of depth perception with late braking or passing the lead car may lead to increased accidents.
3. With head tilting (and the lack of strap slide) the protection of the HANS device may be compromised.
4. All in all, I would prefer not to race a halo car, but if paid to do so, would do the best I could.

### Learning points

- ▶ A unique case report of a driver's first experience with a halo-type structure.
- ▶ Halo-type structures may affect drivers' head position and head movement.
- ▶ It is recommended that the effect of the halo on the muscle activity of the neck is measured, and any negative effects on drivers' head position and head movement are mitigated.

The asymmetrical change in rate of fatigue that occurs with the halo-type structure fitted suggests that the movement pattern of the driver's head is also affected. One possible explanation for the increased rates of fatigue of LSCM and RCES and decreased rate of fatigue of LCES is that the driver tilts his head, perhaps to 'peer around' the central pillar ([Figure 1](#)). When rotating the head from a forward head position, an increase in lateral flexion angle of as little as 2.83° is associated with a significant increase in activation of the contralateral SCM (eg, right head turn/tilt and left SCM).<sup>14</sup> The combination of flexion, lateral flexion and



axial rotation that will occur when rotating the head to steer the vehicle has been associated with acute neck injuries in high-g environments.<sup>8, 19</sup> An accumulation of even minor acute neck injuries may predispose individuals exposed to high g to more frequent and severe neck injuries.<sup>19, 21</sup>

The effects of a change in drivers' head posture go beyond the potential to affect the prevalence of acute and chronic neck injury. Tilting the head, as in the laterally flexed position we observed in our driver, causes an increased sensitivity to roll stimuli which makes a visual scene appear to roll more than it actually is.<sup>22</sup> This has the potential to cause an error in the use of differential motion parallax to accurately locate the position of key visual cues during steering manoeuvres. For example, the ability to accurately locate the position of the apex of a corner is critical in steering a racing line.<sup>7, 23</sup> It is conceivable that other steering manoeuvres such as overtaking and vehicle avoidance could also be affected in a similar manner. The cockpit roll bars of a Formula Mazda are unlikely to limit drivers' head movement to the same extent as the head surrounds of a Formula 1, 2 or Formula E. However, the range of movement available to drivers in these Formulae is certainly sufficient to observe changes in the pattern of neck muscle activation.

The evidence presented here is unique. It suggests that training and/or ergonomic adjustment may be required to mitigate the changes in head position and motion that the driver exhibits during the simulation with a halo-type structure equipped vehicle. First, correcting the tendency to adopt a forward head position will reduce excessive compression loading of the cervical spine. Second, reducing error in the use of differential motion parallax to accurately locate position during steering manoeuvres could potentially reduce the risk of collision during overtaking and cornering. While the exceptionally skilled drivers competing in Formula 1, Formula 2 and Formula E are likely to be able to adapt rapidly to the halo because of the increased ability of experts to transfer perceptual-motor skill in highly time-stressed environments,<sup>24, 25</sup> less-skilled drivers in lower Formulae may not be able to adapt as rapidly or as successfully.

**Contributors** SMR designed the methodology and analysis, collected the data and authored the manuscript. JMM set up the race vehicles, supervised the design and construction of the halo-type structure and coauthored the manuscript.

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**Competing interests** JMM is the president of Raptor Motorsport LLC. This work was funded by Raptor Motorsports. SMR and JMM provide consultancy services to motorsport athletes as R+M.

**Patient consent** Obtained.

**Ethics approval** Ethical approval to publish the case study was sought from and granted by the Institutional Human Research Ethics Committee.

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