Delmuns Carvajal, S.; Fernández-Prieto, I.; Vidal García, E.; Milà-Villarroel, R.; Rey Abella, F.; González-Crespo, C.; Massó-Ortigosa, N. y Giné-Garriga, M. (2023) ELECTROMYOGRAPHIC STUDY OF THE ARMS IN COMPETITIVE KARTING SENIOR CATEGORY DRIVERS. Revista Internacional de Medicina y Ciencias de la Actividad Física y el Deporte vol. 23 (93) pp. 1-15.
DOI: https://doi.org/10.15366/rimcafd2023.93.001

ORIGINAL

ELECTROMYOGRAPHIC STUDY OF THE ARMS IN COMPETITIVE KARTING SENIOR CATEGORY DRIVERS

ESTUDIO ELECTROMIOGRÁFICO DE LOS BRAZOS EN PILOTOS SENIOR DE KARTING DE COMPETICIÓN

Delmuns Carvajal, S.[1,2]; Fernández-Prieto, I.[2]; Vidal García, E.[3]; Milà-Villarroel, R.[1]; Rey Abella, F.[1]; González-Crespo, C.[4]; Massó-Ortigosa, N.[1]; Giné-Garriga, M.[1,2,5]

[1] Blanquerna Faculty of Health Sciences (Universitat Ramon Llull), Department of Physical Therapy. Barcelona (Spain) salvidc@blanquerna.edu; nuriamo@blanquerna.url.edu

[2] Researcher of the Health, Physical Activity and Sport Research Group (SAFE) (Spain) isabelfp.fcsb@gmail.com

[3] Blanquerna Faculty of Health Sciences (Universitat Ramon Llull), Department of Pharmacy. Barcelona (Spain) eulaliavg@blanquerna.edu

[4] Wildlife Ecology & Health Group and Wildlife Ecopathology Service (SEFaS), Veterinary Faculty, Universitat Autònoma de Barcelona (UAB), Department of Medicine and Animal Cirurgy. Bellaterra, Barcelona (Spain) carlosgonzcrespo@gmail.com

[5] Blanquerna Faculty of Psychology, Education and Sport Sciences (Universitat Ramon Llull), Department of Sport Sciences. Barcelona (Spain)

Spanish-English translator: Grace Matthews (Proof-Reading-Service.com), enriquiries@proof-reading-service.com

Código UNESCO / UNESCO Code: 5899 Otras Especialidades Pedagógicas (Educación Física y Deporte)
Clasificación del Consejo de Europa: 4. Educación Física y deporte comparado / Physical Education and sport compared

Recibido 30 de agosto de 2022 **Received** August 30, 2022
Aceptado 12 de octubre de 2023 **Accepted** October 12, 2023

ABSTRACT

The main goal of this cross-sectional study was to assess the muscular activity of the upper limbs in competitive kart drivers while driving in a closed karting circuit, using surface electromyography (EMGS). The most significant muscles of the upper limbs while driving were evaluated in thirteen drivers. Linear mixed models adjusted to a gamma distribution were used to evaluate differences in muscle activity based on the arm, number of laps, track characteristics, and kart type (with/without gears). Significant differences were found between muscle activity according to the type of kart (p <0.0001). Although changes were observed in the mean EMGS values, there were no significant differences between the laps of the circuit or the dominant arm. However, the results showed that there was a significant interaction between the type of kart and the dominant arm (p = 0.021). Muscle activity increased more significantly in the curves traced towards the dominant arms of the drivers.

KEY WORDS: Competitive karting; Electromyography; Muscular activity; Risk of injury; Adolescents.

RESUMEN

El objetivo del estudio transversal fue analizar la actividad muscular de las extremidades superiores en pilotos senior de karting de competición, mediante electromiografía de superficie (EMGS). Se evaluaron los músculos más significativos de las extremidades superiores durante la conducción en trece conductores. Se utilizaron modelos lineales mixtos ajustados a una distribución gamma para evaluar diferencias de actividad muscular en base al brazo, número de vueltas, características del trazado, y tipo de kart (con/sin marchas). Se encontraron diferencias significativas entre la actividad muscular según el tipo de kart (p<0,0001). Aunque se observaron cambios en los valores medios de EMGS, no hubo diferencias significativas entre las vueltas del circuito o el brazo dominante. Sin embargo, los resultados mostraron que hubo una interacción significativa entre el tipo de kart y el brazo dominante (p=0,021). La actividad muscular aumentó de manera más significativa en las curvas trazadas hacia el brazo dominante de los conductores.

PALABRAS CLAVE: Karting de competición; Electromiografía; Actividad muscular; Riesgo de lesiones; Adolescentes.

1. INTRODUCTION

A competition kart is a type of four-wheeled motor sport, in which users begin to compete at a very young age. This sport modality has been the initial training of many current Formula1 drivers (Pick & Cole, 2008). A kart is a land vehicle with or without bodywork, with four non-aligned wheels that are in contact with the ground (track). Two wheels ensure driving and the other two the locomotion. The main parts are the chassis (includes the bodywork), the tires, and the engine (Rosalie & Malone, 2019).

Karting has been endowed with strict rules to compete, among them those related to safety. The safety equipment should be officially approved, technically checked, and adjusted to each driver, as well as the seat and pedals (A; Pick & Cole, 2008; Rosalie & Malone, 2019). Even though its competitive practice poses several risks (Hoyes & Collins, 2018), there are few studies addressing the incidence, the cause and severity of injuries. A study conducted with drivers aged between seven and fifteen years assessed the type and severity of injuries suffered in competitive karting in Catalonia, Spain, and concluded that the incidence of injuries had been relatively low (Backman, Häkkinen, Ylinen, Häkkinen, & Kyröläinen, 2005). However, injuries are located mostly in the upper limbs and, to our knowledge, there are no previous studies assessing the risk of injuries in competitive karting. Studies have found much greater incidence of injuries in leisure karting, some of which were considered serious (Abernethy, Schorer, Jackson, & Hagemann, 2012; Durand, Ripamonti, Rahmani, & Beaune, 2015; Hernández Hernánez, Oña Sicilia, Bilbao, Ureña, & Bolaños, 2011).

Surface electromyography (SEMG) has been widely used in clinical practice to assess and record the electrical activity produced by skeletal muscles (Abernethy et al., 2012; Criswell, 2010; Durand et al., 2015; Hernández Hernánez et al., 2011). Specifically, the applications of SEMG within the field of sport are assessment of gestures, gait, fatigue, and muscle activity during a diagnostic or therapeutic process. This way, it facilitates myofeedback techniques, evaluation of sports performance, assessment of neuromuscular disorders and coactivation (Balestra, Frassinelli, Knaflitz, & Molinari, 2001; Dario Farina, 2006; Lopez-Valenciano, Biviá-Roig, Lison-Parraga, & Vera-Garcia, 2013).

Electromyographic signals are directly related to muscular strength (Garcia & Vieira, 2011; Karlsson, Yu, & Akay, 2000; Massó et al., 2010). SEMG has acquired increasing importance in sports medicine and in ergonomic studies (D Farina, Stegeman, & Merletti, 2016), as well as establishing dynamic analysis for sport performance (De Luca & Merletti, 1988).

Based on the lack of related studies, the main goal of our study was to assess muscular activity in the upper limbs of adolescent drivers performing in karting competitions (senior category) during their driving action, assessed using SEMG. Specifically, we intended to: (a) assess muscle activity differentials based on the number of laps performed, noting possible evidence of muscle fatigue; (b) assess the differences in SEMG values of the drivers' arms according to the different driving tasks in the circuit; (c) determine the interrelationships between the different muscles of the arms when driving competition karts; (d) compare the differences between muscular activity patterns of the arms, according to the driving tasks and actions depending on the type of kart layout; and (e) observe the effect of the type of kart (with or without gears) on the muscular activity of each muscle group in both arms considering each type of circuit sector.

2. METHODS

2.1 PARTICIPANTS

Thirteen drivers participated in the present study (mean = 16.7 years old; range = 14-18). Four of them drove the two types of karts (with and without gears), and the rest of the drivers drove karts without gears. Two drivers were left-handed and eleven right-handed.

The objectives and characteristics of the study were previously reported to the Sallent Karting Circuit Drivers Association, which was in charge of inviting all the drivers who met the inclusion criteria. The participants were informed about the rights granted by the data protection law and signed the corresponding informed consent forms. The forms were signed by their parents or legal guardians. The study was approved by the Research Ethics Committee of the Blanquerna Faculty of Psychology, Education and Sports Sciences (Ramon Llull University).

The inclusion criteria for the selection of the participants were: (a) belonging to the Karting senior category based on the competition regulations of the International Karting Committee, and in force in the Catalan Karting Championship; (b) not receiving treatment for injuries of the upper limbs; (c) not having previously suffered any injury in the upper limbs; (d) participants should know the layout of the Sallent Karting Circuit.

2.2 CHOICE OF MUSCLES

Karting requires the activity and participation of the upper limb muscles, according to the driver grip on the steering wheel, and the rotation into the curves that each driver performs, in addition to the layout (curves) of the circuit. Based on these parameters, the most significant muscles were selected for assessing both arms, taking into account the following criteria:

(1) prioritising large muscles (which are the most active); (2) use the total available channels of the electromyograph, specifically two muscles per emitter, having four emitters, with eight muscles being analysed at the same time (4 muscles per arm); (3) selection of muscles that maintain an agonist/antagonist relationship to have their most significant muscular activities on the sequences in the performance required for driving; (4) that the selection of these muscles and the location of the electrodes for SEMG, as well as the arrangement of the wireless signal transmitters, should be compatible without altering the driving action of the kart.

The selected muscles were: a) Forearm flexor muscle: superficial and deep finger flexors, flexor carpi (ulnaris and radialis), and long flexor muscle of the thumb. They were abbreviated as FCRS (for the right arm) and FCLS (for the left arm); b) Forearm extensor muscle: extensor digitorum, brachioradialis, extensor carpi radialis (longus and brevis). They were abbreviated as ECRS (for the right arm) and ECLS (for the left arm); c) Biceps brachii. It was abbreviated as BBRS (for the right arm) and BBLS (for the left arm); d) Round pronator muscle (teres minor). It was abbreviated as PRS (for the right arm) and PLS (for the left arm).

2.3 CIRCUIT

The division of the circuit in 11 sectors (Figure 1) facilitated the analysis of EMG and images 'on board'. The locations of the karts during the test were obtained using the information from the 'set' of EMG records. Each sector had driving demands to follow the competition layout. The description of each sector and location of the 'set' of EMG records, and track coordination is detailed in Figure 1.

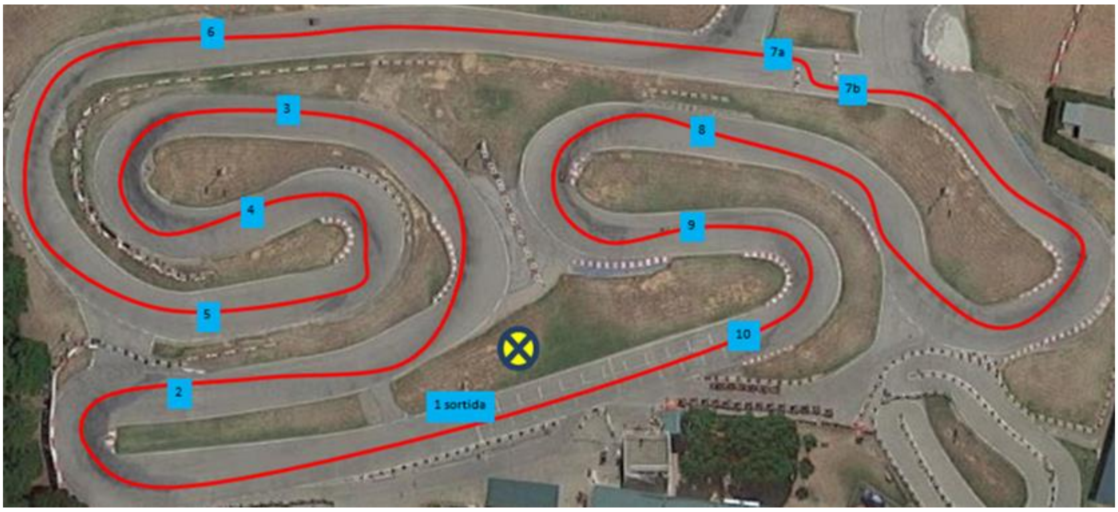

Figure 1. Detail of the different sectors of the Sallent Karting Circuit. The study was conducted respecting the usual sense of competition, using the approved layout for competitions.

Note. Sector 1-2: Main exit straight with a sharp right curve after braking at the end of the straight; Sector 2-3: Long and open left curve; Sector 3-4: Sharp left curve; Sector 4-5: Sharp right curve; Sector 5-6: Open right curve; Sector 6-7: Second long straight of the circuit; Sector 7a-7b: Chicane (fast turns after the straight); Sector 7b-8: Double curve to the right until a slight curve to the left; Sector 8-9: Sharp curve to the left; Sector 9-10: Sharp curve to the right to link with sector 1; Goal: Straight-Detail of the location of the EMG records set and coordination of the karting circuit. Figure 4 shows the circuit and its different sectors.

2.4 PROCEDURE

Once the study protocol was designed and approved, we selected the muscles in which the EMG readings would be collected. The choice of muscles was determined based on a review and watching competition driving videos from on-board cameras, which served to make a visual review of the most common actions of the upper limbs of the drivers performing in the circuits. The problems of electrode placement and emitting equipment were also analysed, as well as the location in the circuit and processing of the EMGS signals, following the recommendations of the biomechanics expert with the reception team at the time the participants were driving their karts.

With the signed authorisation of the director of the Sallent Karting Circuit, the security measures were reviewed together with the track team members. A document specifically designed was used to collect the data. Karts without and with gears were used for the senior category of the Catalan Karting Championship. All drivers used the same personal safety equipment, and wore regulatory clothing approved under the current International Karting Committee regulations. The items used were: bandages for electrode placement and EMG signal emission equipment (EMGS Ag-AgCl electrodes, model EL503 from Biopac); HP laptop for signal reception in the karting circuit (computer software: Excel, SPSS 21.0); GoPro 7 Black camera fixed on the drivers' helmets, with HD recording, 1080p resolution, and 60 frames per second; and an MP150 surface electromyograph with AcqKnowledge 4 software from Biopac Systems, California, USA. The recording frequency was 1000 Hz. The signal collected from each channel was filtered with a 10Hz-500Hz pass-band and a smoothing algorithm, based on the root mean square (RMS), which was applied with a window length of 50 ms. The mean amplitude of the SEMG signal was collected by processing marked intervals on the karting circuit layout from one to ten. The electrodes were placed on the muscle bellies, choosing the reference anatomical locations described by Eleanor Criswell (Kamen, 2010). The placement of the electrodes was performed by the same researcher in order to avoid possible modifications in the placement and collection of the SEMG signal.

A maximal isometric contraction of all target muscle structures was requested to the drivers. This previous measurement of the isometric contraction record was performed to have the reference of maximum muscle activity, this value being a key for the subsequent recording and analysis of muscle activity when driving in the circuit. This verification and registration process was always carried out by the same two researchers. Then, each driver received the specific details related to the test: the first lap was used as a warm-up and recognition of the circuit layout, as well as to check the correct emission and reception of the signal from the SEMG team. Subsequently, the drivers were asked to attempt the maximum driving performance during the next three laps of the circuit, pretending they were competing in each one of them. This protocol was complemented with the recording of videos by the GoPro on-board cameras, fixed on the helmet of each driver, focusing specifically on the drivers' arms, and recording all the movements made in the three laps of the circuit, sector by sector and curve by curve. Once the drivers were in the circuit, communication was done through the use of competition boards at the trackside. The on-track experimentation phase began on 27th October 2017, and the last SEMG data collection session ended on 16th February 2018.

2.5 DATA ANALYSIS

A descriptive analysis was used for all the data collected in the EMG data records. In the case of the variable 'EMG muscle response', it was determined whether the data followed a normal distribution using the Shapiro-Wilk test, together with the normality graphs (Q-Q plot) and the asymmetry and kurtosis statistics. The variable 'EMG' showed significant violations of the principles of normality, with strong asymmetries and positive kurtosis, following a gamma distribution. In order to minimise these asymmetries, some transformations were tested, such as square root, base-10 logarithm (Log10) and Nepierian logarithm (In), but these asymmetries were not completely minimised. Therefore, all the descriptive variables were explained by median (Md), interquartile range (IQR), and maximum and minimum value. The categorical variables were described by frequencies and percentages. We used generalised linear mixed models (GLMM) fitted to a gamma distribution. Tukey test was used to assess the differences between the factors of each explanatory variable and the interactions between variables. The first model was used to assess whether there were significant differences in muscle activity relating to the type of kart (with gears and without gears), the number of laps, and the characteristics of the drivers (dominant arm, right-handed or left-handed). The measurements of each driver were considered as a nested factor within the random factor 'driver', so that the statistical model could interpret that each sample (lap) was associated with a sample unit (driver) and were not independent measures.

In order to perform a more specific analysis, a second model was used to assess whether there were significant interactions and differences in EMG muscle activity of each of the muscle groups studied in both arms, and related to the type of circuit sector (categorised into four categories: (1) Left curve (LC) = (Sector 3-4); Right curve (RC) = (Sector 4-5); Straight (ST) = (Sector 1-2); and Chicane (CH) = (Sector 7a-7b). Then, both models were combined in order to determine the effect, according to the type of kart (with or without gears), on the muscular activity of each muscle group, in both arms for each type of circuit sector. Finally, two sharp curves were selected, one on the left (LC) (Sector 3-4) and the other on the right (RC) (Sector 4-5) to analyse whether there were significant interactions and differences in muscle activity of each muscle group of the arms that corresponded to the direction of the curves, with respect to the drivers' dominant arm (left-handed or right-handed) in karts without gears. A significance level of 5% ($\alpha = 0.05$) was used in all the statistical tests performed. The statistical programme R-Studio version 1.1.383 (RStudio, Inc. with the lme4 and emmeans packages) was used for the statistical analysis of the data.

3. RESULTS

3.1 GENERAL MUSCULAR ACTIVITY IN PILOTING TECHNIQUE

The results obtained in the analysis of the first model (Table 1; Figure 2) indicated that there was statistical significance in the comparison of muscle activity with respect to the type of kart (p <0.0001). Even though changes were observed in the mean EMG values, there were no significant differences between the laps of the circuit (p = 0.647), nor the dominant arm (p = 0.431). However, the results indicated that there was a statistically significant interaction between the type of kart (with and without gears) and the dominant arm (p = 0.021), showing significant differences between the two types of karts for each dominant arm (p <0.0001). Based on the results of this interaction, a left-handed driver using a kart with gears reached almost twice the performance in muscular work (p = 0.076) than a right-handed driver with the same type of kart (p = 0.043).

Table 1. Differences between mean values of EMG (in mV) activity with respect to (a) lap, (b) dominant arm, (c) type of kart (with or without gears), and (d) interaction of the factors of the variables 'dominant arm' and 'type of kart'.

Variable	Contrast	Difference (mV)	z. ratio	*p* value
Lap (*p* = 0.647)	L1-L2	0.001	0.011	0.999
	L1-L3	0.043	0.815	0.694
	L2-L3	0.042	0.805	0.699
Dominant arm	LA - RA	0.239	0.788	0.431
Type of kart	Yes - No	0.599	8.378	<0.0001
Interaction between dominant arm and gears (*p* = 0.021)	LA, Yes LA, No	0.765	6.218	<0.0001
	RA, Yes RA, No	0.433	5.941	<0.0001

Note. L1 = lap 1; L2 = lap 2; L3 = lap 3; LA = left arm; RA = right arm.

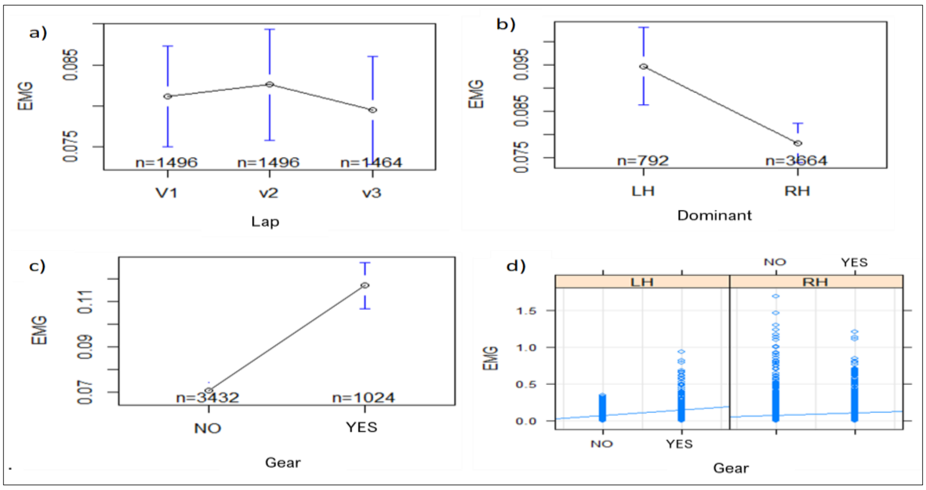

Figure 2. Mean values of EMG (in mV) activity for (a) lap; (b) dominant arm; (c) type of kart (with or without gears); and (d) interaction of the factors of the variables ‘dominant arm’ and ‘type of kart’.

Note. Blue line indicates the trend and the mean at the intersection.
L1 = lap 1; L2 = lap 2; L3 = lap 3; LA = left arm; RA = right arm.

3.2 SPECIFIC MUSCLE ACTIVITY IN DRIVING TECHNIQUE

The analysis of the second model indicated statistical significance in the results obtained (Table 2; Figure 3) by the comparison of muscle activity in each muscle group assessed in both arms (p <0.0001) and with respect to the type of circuit sector (4 categories: left curve, right curve, straight, and chicane) (p <0.0001).

Table 2. Differences between mean values of (a) EMG (in mV) activity of the muscles of the right and left arms of each driver, and (b) type of circuit sector

Variable		Contrast	Difference (in mV)	z. ratio	*p* value
	Between arms	BBLS-BBRS	-0.798	-9.329	<0.0001
		ECLS-ECRS	-0.859	-10.228	<0.0001
		FCLS-FCRS	-0.994	-11.624	<0.0001
		PLS-PRS	-1.257	-14.748	<0.0001
Muscle (*p* <0.0001)	**Left arm BBLS[a] ECLS[b] FCLS[c] PLS[b-c]**	BBLS-ECLS	0.290	3.431	0,014
		BBLS-FCLS	0.538	6.37	<0,0001
		BBLS-PLS	0.351	4.173	0.001
		ECLS-FCLS	0.251	3.042	0.048
		ECLS-PLS	0.064	0.769	0.995
		FCLS-PLS	-0.187	-2.253	0.320
	Right arm BBRS[a] ECRS[a-b] FCRS[b] PRS[a]	BBRS-ECRS	0.226	2.731	0.113
		BBRS-FCRS	0.342	4.137	0.001
		BBRS-PRS	-0.108	-1.299	0.899
		ECRS-FCRS	0.116	1.391	0.862
		ECRS-PRS	-0.335	-4.012	0.002
		FCRS-PRS	-0.451	-5.367	<0.0001
Type of circuit sector (*p* <0.0001) RC[c]-LC[a]-CH[c]-ST[b]		RC-CH	0.080	0.987	0.757
		RC-LC	-0.366	-6.743	<0.0001
		RC-ST	-0.167	-3.065	0.012
		CH-LC	-0.445	-5.356	<0.0001
		CH-ST	-0.250	-2.985	0.015
		LC-ST	0.198	3.417	0.004

Note. a, b, c = Factors with different superscripts are statistically different (p <0.05).
BB = biceps; EC = extensor; FC = flexor, P = pronator; LS = left side; RS = right side; RC = right curve; LC = left curve; CH = chicane; ST = straight.

The results obtained in the comparison of the mean values of EMG activity in the muscle groups assessed in both arms (Table 2) indicated significant differences between the right and left arms for the same muscle group. In the left arm, there were significant differences between all the muscle groups, except between ECLS-PLS and FCLS-PLS. In the right arm, the highest value belonged to PRS and the lowest to FCSR, with significant differences between BBRS-FCRS, ECRS-PRS, and FCRS-PRS. The results indicated significant differences between the mean values of EMG activity in each type of sector except between CD-CH, being classified into three levels based on the EMG values (from highest to lowest): a) CI; b) RE; c) CD & CH.

The results obtained show that, in the second model, there were statistically significant interactions (Figure 3) between the muscle groups in both arms of each pilot and the type of circuit sector (p <0.0001), which indicated significant differences between the muscles in each type of sector, and in each muscle group between sector types.

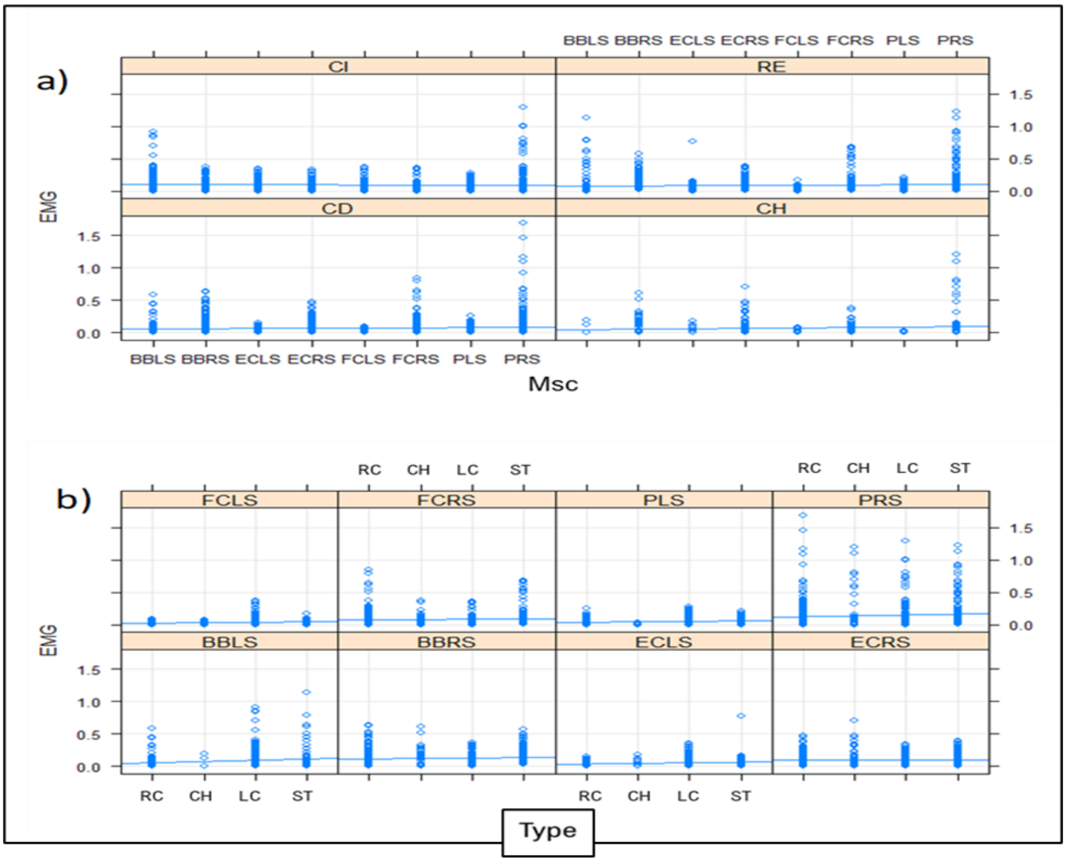

Figure 3. Mean values of EMG (in mV) activity of the muscles of the right and left arms of each driver, for each type of sector.

Note. (a) EMG (in mV) activity of all muscle groups in each type of circuit sector; (b) EMG (in mV) activity of each muscle group in all types of circuit sectors. Blue line indicates the trend and the mean at the intersection.

Msc = muscle; BB = biceps; EC = extensor; FC = flexor, P = pronator; LS = left side; RS = right side; RC = right curve; LC = left curve; CH = chicane; ST = straight.

The comparison of the mean values of EMG activity in the muscle groups between both arms, for each type of circuit sector, indicated significant differences between the same muscle group of the left and right arms, in each type of circuit sector (RC, CH, ST; $p < 0.0001$), except for all muscle groups driving into the left curves (LC), with mean EMG values higher in the left arm than in the right one.

3.3 DIFFERENCES AND INTERACTIONS BETWEEN MUSCLE GROUPS DEPENDING ON THE CIRCUIT SECTOR

We compared the mean values of the EMG activity in each muscle between the different types of circuit sector (Table 3) and found that there were significant differences for all the muscles of the left arm ($p < 0.0001$ in all the muscles), but there were no significant differences in none of the muscles of the right arm. When we compared the mean values of the EMG activity between the different muscles for the same type of circuit sector, we found that there were significant differences in the activity of the muscle groups in each type of sector.

Table 3. Mean values of EMG (in mV) activity and differences between the muscle groups of the right and left arms of each driver, for each type of sector.

Muscles	Right curve (in mV)	Left curve (in mV)	Chicane (in mV)	Straight (in mV)	Differences in EMG (in mV) activity of the same muscle between types of circuit sectors
BBLS	0.042 $^{(b, 2)}$	0.149 $^{(a, 1)}$	0.010 $^{(c, 3)}$	0.070 $^{(b, 2)}$	0.076 (p <0.0001)
ECLS	0.032 $^{(b, 2)}$	0.095 $^{(a, 1)}$	0.017 $^{(c, 2)}$	0.033 $^{(b, 2-3)}$	0.048 (p = 0.0011)
FCLS	0.022 $^{(b, 2)}$	0.081 $^{(a, 1-2)}$	0.010 $^{(c, 2-3)}$	0.022 $^{(b, 3)}$	0.037 (p <0.0001)
PLS	0.032 $^{(b, 2)}$	0.095 $^{(a, 1)}$	0.001 $^{(c, 4)}$	0.030 $^{(b, 3)}$	0.046 (p <0.0001)
BBRS	0.117 $^{(a, 1)}$	0.095 $^{(a, 2)}$	0.120 $^{(a, 1)}$	0.148 $^{(a, 1)}$	0.120 (p = 0.5057)
ECRS	0.090 $^{(a, 1)}$	0.080 $^{(a, 1-2)}$	0.126 $^{(a, 1)}$	0.105 $^{(a, 1)}$	0.094 (p = 0.918)
FCRS	0.087 $^{(a, 1)}$	0.051 $^{(b, 2)}$	0.076 $^{(a-b, 1)}$	0.106 $^{(a, 1)}$	0.081 (p = 0.9212)
PRS	0.124 $^{(a, 1)}$	0.139 $^{(a, 1)}$	0.170 $^{(a, 1)}$	0.176 $^{(a, 1)}$	0.146 (p = 0.1167)
Differences in EMG (in mV) activity between muscles (same type of circuit sector)	0.068 (p <0.0001)	0.098 (p <0.0016)	0.066 (p <0.0001)	0.086 (p <0.0035)	

Note. a, b, c, 1, 2, 3, 4 = values in cells with different superscripts are statistically different (p <0.05). Letters indicate differences between values in the same row. Numbers indicate differences between values in the same column.

BB = biceps; EC = extensor; FC = flexor; P = pronator; LS = left side; RS = right side.

3.4 DIFFERENCES DEPENDING ON THE TYPE OF KART IN EACH TYPE OF CIRCUIT SECTOR

The results obtained by the analysis of the third model (Table 4) indicated that there was statistical significance when comparing the muscle activity of each muscle group assessed in both arms ($p < 0.0001$) with respect to the type of circuit sector ($p < 0.0001$) and the type of kart ($p = 0.002$).

There were statistically significant interactions between the muscle groups in both arms of each driver and the type of circuit sector ($p < 0.0001$), between the muscle groups in both arms of each driver and the type of kart ($p < 0.0001$), between the type of kart (with or without gears) and the type of circuit sector (*p* <0.0001), and between the muscle groups, the type of kart, and the type of circuit sector (*p* <0.0001).

The analysis of the effect of kart type on the EMG activity of the muscle groups in each type of circuit sector indicated that the type of kart had a significant effect on all muscles and in all types of sectors, except ECRS in LC, FCRS in CH, and FCLS in ST.

Table 4. Differences between mean values of EMG (in mV) activity in the muscle groups of the right and left arms of each driver, for each type of kart (with or without gears).

Contrast/gears (No-Yes)	**Right curve (in mV)**	**Left curve (in mV)**	**Chicane (in mV)**	**Straight (in mV)**
BBLS	0.435 (*p* <0.0001)	0.116 (*p* = 0.009)	-3.577 (*p* <0.0001)	0.950 (*p* <0.0001)
ECLS	-0.360 (*p* <0.0001)	-0,399 (*p* <0.0001)	-0,739 (*p* <0.0001)	0.320 (*p* <0.0001)
FCLS	-0.417 (*p* <0.0001)	-0.340 (*p* <0.0001)	-0,459 (*p* <0.0001)	-0.020 (*p* = 0.768)
PLS	-0.156 (*p* = 0.0013)	-0.358 (*p* <0.0001)	-1.760 (*p* <0.0001)	0.490 (*p* <0.0001)
BBRS	0.118 (*p* = 0.008)	0.619 (*p* <0,0001)	1.228 (*p* <0,0001)	0.594 (*p* <0,0001)
ECRS	-0.323 (*p* <0.0001)	0.099 (*p* = 0.666)	0.267 (*p* = 0.0001)	0.593 (*p* <0.0001)
FCRS	0.729 (*p* <0.0001)	0.678 (*p* <0.0001)	0.106 (*p* = 0.124)	1.294 (*p* <0.0001)
PRS	0.509 (*p* <0.0001)	0.521 (*p* <0.0001)	1.999 (*p* <0.0001)	0.797 (*p* <0.0001)

Note. BB = biceps; EC = extensor; FC = flexor; P = pronator; LS = left side; RS = right side.

3.5 DIFFERENCES AND INTERACTIONS BETWEEN MUSCLE GROUPS IN THE ARMS CORRESPONDING TO THE DIRECTION OF THE CURVES

Finally, in the fourth model, in which two sharp curves were selected, one on the left (LC; sectors 3-4) and the other on the right (RC; sectors 4-5), for karts without gears, the analysis of the differences in the muscle activity of each muscle group in the arms corresponding to the direction of the curves, with respect to the drivers' dominant arm, indicated that, in both analyses, there was statistical significance in the muscle group (LC, *p* <0.0001; RC, *p* = 0.000); however, there were no differences with respect to the dominant arm (LC, *p* = 0.293; RC, *p* = 0.971).

The results indicated that there were significant differences in muscle activity when comparing the EMG activity of BBLS-ECLS, BBLS-FCLS, ECLS-PLS, FCLS-PLS driving into the LC, and BBRS-FCRS and FCRS -PRS into the RC. There were no significant differences in the muscular activity of the rest of the muscle groups, nor when comparing left-handed and right-handed drivers (Table 5).

Table 5. Differences between EMG (in mV) activity values of the muscle groups in the arms corresponding to the directions of the curves and the dominant arms. Only meaningful comparisons are included.

Arm-Curves Muscles	Contrast	Difference (in mV)	z. ratio	*p* value
Left arm - Left curves BBLS[a]-ECLS[b]-FCLS[b]-PLS[a]	BBLS-ECLS	1.423	3.646	0.002
	BBLS-FCLS	1.512	4.079	0.000
	BBLS-PLS	0,1.2	0.498	0.960
	ECLS-FCLS	0.089	0.242	0.995
	ECLS-PLS	-1.241	-3.257	0.006
	FCLS-PLS	-1.330	-3.685	0.001
Right arm - Right curves BBRS[a]-ECRS[a-b]-FCRS[b]-PRS[a]	BBRS-ECRS	0.291	2.078	0.160
	BBRS-FCRS	0.493	3.514	0.003
	BBRS-PRS	-0.052	-0.368	0.983
	ECRS-FCRS	0.202	1.458	0.463
	ECRS-PRS	-0.343	-2.400	0.077
	FCRS-PRS	-0.545	-3.800	0.001

Note. a, b = factors with different superscripts are statistically different ($p < 0.05$).
BB = biceps; EC = extensor; FC = flexor; P = pronator; LS = left side; RS = right side.

4. DISCUSSION

The results obtained in the present study indicated differences in muscle activity assessed with EMG of the muscles selected in the upper limbs for driving karts with and without gears. Muscle activity increased most significantly when the curves were traced on the drivers' dominant sides (Clark, 2015). No muscle fatigue markers were found, and studies with more mileage on the circuit are necessary to detect possible muscle fatigue in the arms of competition kart drivers. A specific study on competition karting that assessed metabolic energy expenditure and heart rate response found that at least a 45-minute ride was required to reach 82% of the maximum heart rate, suggesting the need for a greater number of laps (Adler, 2000).

Our results indicated that the dominant side of the drivers did not prevail over the voluntary motor activity of the arm on the same side as the direction of the curve (Ahmad et al., 2011; Bley & Gahr, 2002). This fact was possibly due to a process of anticipation. In sport, it is defined as the ability to predict behaviours thanks to the perception and synchronisation of synaptic interconnections that give rise to movements. This way, these movements give a rapid response after the performance of a filtering for the correct actions at the right time, thus improving sports action (Delmuns, Roig, Javierre Garcés, Mans, & Giné-Garriga, 2014). This ability to anticipate has been established as one of the greatest skills that athletes acquire due to the sensitivity of perception and the ability to capture and process information in a limited time (Muñiz Fontán, Martinón Torres, & Rodríguez Núñez, 2010). The results obtained allowed us to consider the automated system described as a useful tool for sports research and future applications in training programmes and injury prevention (D, 2019). In karts with gears, the muscles of the left arm follow the layout of the circuit and positioning of the kart, while the right arm selects the gears using the gear lever and punctually grasping the steering wheel (Dmitriev, Bayazitov, Korznikova, Bachurin, & Zinovev, 2020). The results of the SEMG signals indicated greater muscle activity when driving karts with gears than that applied in karts without gears, including their technical and mechanical performance differentials. In karts without gears, both hands grip on the steering wheel permanently, symmetrically performing the same muscular work in both arms. The results of this study can facilitate more specificity in the training and physical preparation of the drivers according to the type of kart they use. In addition, they indicate the need to design specific training programmes, as suggested in previous studies (D, 2019; Sanches, 2011).

The results of the present study confirm the importance of the biceps brachii muscle for driving karts. This muscle is biarticular and its action is related to elbow flexion, shoulder flexion, and supination, which allows alternating asymmetric movement when both hands are gripping the wheel. This is a key action when driving karts without gears, given that both hands grip on the wheel throughout the circuit, unlike karts with gears (Sanches, 2011).

This greater activity of the muscle groups of the right arm may have its origin in the use of the gear lever of karts. The need for pronation in the release and grip of the gear lever of this type of karts provided results that show key differences for driving the two types of competition karts. It should be noted that the layout of the circuit where the study was conducted always has RC at the end of ST. The results of the present study indicated voluntary muscle activation of the same arm on the side of the curves traced on the drivers' dominant side, for all types of curves. This fact was possibly due to the same anticipation process described above (20). Simon et al. (2019) recently published a study conducted in a simulator with four formula drivers. They found changes in visual behaviour or cervical mobility and anticipation in drivers without vehicles ahead of them (free track) or with them (pursuit). Our study found a reduction in fatigue rates in the neck muscles when drivers followed another vehicle, suggesting a reduction in head movements when taking that vehicle as reference/anticipation (D, 2019).

With respect to the left arm, in LC, increased activity was observed in the BBLS and ECLS muscles with the PLS of the same left arm, and also the PRS of the right arm. Based on these results, the aforementioned finding was also repeated and ratified with respect to muscle activation on the same side of the direction of the curve (D Farina et al., 2016; Massó et al., 2010). Outstandingly, the PRS of the right arm seemed to assist steering wheel motion in LC (Sanches, 2011). The muscular activity of all muscles of the right arm in ST was higher than in RC for the same arm, without significant differences. This finding can be explained by the aforementioned due to neurological anticipation, and because it is in the straights where there is maximum power delivery and maximum speed with maximum deceleration due to final braking (D Farina et al., 2016; Massó et al., 2010).

A major limitation of the present study was that the sample consisted of a little number of drivers. Another limitation was the number of laps assessed, which was insufficient to detect symptoms of fatigue. The selection of the muscles studied with EMG in the present study can be useful for further studies addressing different modalities of motor racing. Anticipation relating to the type of curve, which prevails over the dominant arm of the drivers, is an important finding. As a whole, it allows planning physical preparation programmes for the prevention of injuries and improvement of sports performance, with greater specificity for kart drivers. The muscular activity of both arms in the karts without gears did not exhibit significant differences. In karts with gears, the left arm controls the vehicle through the steering wheel, while the right arm controls the gear lever. In the left-handed drivers, a greater electromyographic activity was detected in the right arm (non-dominant arm), indicating a possible ergonomic alternative in the design of karts for left-handed drivers with the gear lever on the left side. Further studies should take into account the expansion of the number of laps, in order to assess muscular activity at the moment of the onset of fatigue in the studied muscles.

ACKNOWLEDGMENTS

We appreciate the support of all volunteer participants.

REFERENCES

A, N. Kinesiology of the musculoskeletal system: foundations for rehabilitation. 2da ed. Mosby: Elsevier. *2016*, 422.

Abernethy, B., Schorer, J., Jackson, R. C., & Hagemann, N. (2012). Perceptual training methods compared: the relative efficacy of different approaches to enhancing sport-specific anticipation. *Journal of experimental psychology: Applied, 18*(2), 143.

Adler, P. (2000). Go-kart related injuries and death to children. *Consumer Product Safety Commission, 48*.

Ahmad, M., Sinha, P., Al-Tamimi, Y. Z., Sylvester, D., Dezso, A., & Timothy, J. (2011). The Isadora syndrome: a case report of cervical, oesophageal and tracheal transection in a go-karting accident. *British journal of neurosurgery, 25*(2), 310-312.

Backman, J., Häkkinen, K., Ylinen, J., Häkkinen, A., & Kyröläinen, H. (2005). Neuromuscular performance characteristics of open-wheel and rally drivers. *The Journal of Strength & Conditioning Research, 19*(4), 777-784.

Balestra, G., Frassinelli, S., Knaflitz, M., & Molinari, F. (2001). Time-frequency analysis of surface myoelectric signals during athletic movement. *IEEE Engineering in Medicine and Biology Magazine, 20*(6), 106-115.

Bley, T., & Gahr, R. (2002). Risks and injuries of go-karting. *Zentralblatt fur Chirurgie, 127*(6), 523-526.

Clark, B. (2015). Modelling the evolution and expected lifetime of a deme's principal gene sequence. *Letters in Biomathematics, 2*(1), 13-28. doi:https://doi.org/10.30707/LiB2.1Clark

Criswell, E. (2010). *Cram's introduction to surface electromyography*: Jones & Bartlett Publishers.

D, F. (2019). Campionats, copes, trofeus i challenges de catalunya de kàrting reglament esportiu. *1*(1), 1–31.

De Luca, C. J., & Merletti, R. (1988). Surface myoelectric signal cross-talk among muscles of the leg. *Electroencephalography and clinical neurophysiology, 69*(6), 568-575.

Delmuns, S., Roig, M., Javierre Garcés, C. F., Mans, C., & Giné-Garriga, M. (2014). Epidemiological study of injuries Arising from karting competition in children. *Journal of Community Medicine and Health Education, 2014, vol. 4, núm. 4*.

Dmitriev, S. V., Bayazitov, A. M., Korznikova, E. A., Bachurin, D. V., & Zinovev, A. V. (2020). Dynamics of supersonic N-crowdions in fcc metals. *Reports in Mechanical Engineering, 1*(1), 54-60.

Durand, S., Ripamonti, M., Rahmani, A., & Beaune, B. (2015). Bioenergetical and cardiac adaptations of pilots to a 24-hour team kart race. *The Journal of Strength & Conditioning Research, 29*(11), 3234-3239.

Farina, D. (2006). Interpretation of the surface electromyogram in dynamic contractions. *Exercise and sport sciences reviews, 34*(3), 121-127.

Farina, D., Stegeman, D., & Merletti, R. (2016). Biophysics of the generation of EMG signals. *Surface electromyography: physiology, engineering, and applications*, 1-24.

Garcia, M. C., & Vieira, T. (2011). Surface electromyography: Why, when and how to use it. *Revista andaluza de medicina del deporte, 4*(1), 17-28.

Hernández Hernánez, E., Oña Sicilia, A., Bilbao, A., Ureña, A., & Bolaños, J. (2011). Efecto de la aplicación de un sistema automatizado de proyección de preíndices para la mejora de la capacidad de anticipación en jugadoras de voleibol. *Revista de Psicología del deporte, 20*(2), 0551-0572.

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.

Kamen, G. (2010). Essentials of electromyography. *(No Title)*.

Karlsson, S., Yu, J., & Akay, M. (2000). Time-frequency analysis of myoelectric signals during dynamic contractions: a comparative study. *IEEE transactions on Biomedical Engineering, 47*(2), 228-238.

Lopez-Valenciano, A., Biviá-Roig, G., Lison-Parraga, J., & Vera-Garcia, F. (2013). Electromyographic study of trunk flexion exercises on inclined board. *Revista Internacional de Medicina y Ciencias de La Actividad Fisica y Del Deporte, 13*(52), 657-671.

Massó, N., Rey, F., Romero, D., Gual, G., Costa, L., & Germán, A. (2010). Aplicacions de l’electromiografia de superfície a l’esport. *Apunts. Medicina de l'Esport, 45*(166), 127-136.

Muñiz Fontán, M., Martinón Torres, N., & Rodríguez Núñez, A. (2010). ¿ Son seguros los karts? *An. pediatr.(2003, Ed. impr.)*, 91-92.

Pick, A. J., & Cole, D. J. (2008). A mathematical model of driver steering control including neuromuscular dynamics.

Rosalie, S., & Malone, J. (2019). Do racing drivers practice racing? The effect of intentional following on formula car drivers’ steering behaviour. *Journal of Expertise, 2*(3), 164-183.

Sanches, J. D. (2011). *The karting manual: the complete beginner's guide to competitive kart racing*: Haynes.