

## Radio-Controlled Car Operation Level Estimation with Physiological Index

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**Abstract.** Radio-controlled (RC) car is an interesting leisure activity. RC car motion is controlled by operator's hand. Left hand is to control the throttle and the right hand is to control the direction. A novel physiological index to assess the learning level of operator is proposed in this article. Twelve expert groups and 11 novice groups participated. Surface Electromyography (sEMG) of hands, heartbeats and the numbers of eye blink were measured to compare the differences between an expert group and a novice group. RC Car rap times were measured on three track types; hairpin corner, drag strip and S-bend. The average speed of expert and novice groups are  $47.1 \pm 3.2$  km/hr and  $24.2 \pm 4.3$  km/hr ( $p < 0.001^{***}$ ). The heartbeats of the expert group were slower than those of the novice group ( $738.95 \pm 26.63$  ms vs.  $680.50 \pm 61.4$  ms,  $p = 0.005^{**}$ ). The eye blinking rate of the expert group is less than that of the novice group ( $0.79 \pm 0.65$  vs.  $1.84 \pm 0.63$ , blinks/min,  $p < 0.001^{***}$ ). Muscle activity of hairpin corner are  $3.74 \pm 1.06$  and  $2.70 \pm 0.52$  for expert group and a novice group ( $p < 0.001^{***}$ ), median frequency of muscle activity of hairpin corner are  $183.64 \pm 42.22$  and  $220.34 \pm 19.87$  for expert group and a novice group ( $p < 0.001^{***}$ ). This study investigated that expert group can control RC car with higher attention, and delicate muscle contraction to gain a better RC rap time performance.

### Introduction

Biomedical signals, such as electromyography, originated from muscle contraction, are widely used to measure body motion. An interesting application of motion control measurement is for sports, using contemporary equipment and information technology to facilitate improving effectiveness in sports. Numerous devices have been employed to detect physiological and psychological changes in athletes to serve as foundations for improving and applying training [1, 2]. In the Ermes et al. study [3], bicycling was investigated and the degrees of muscle response in the upper and lower limbs were analyzed. Lin et al. [4] applied electromyography (EMG) data from the wrists and determined that an angle of  $21^\circ$  led to high hit rates, but increased muscle fatigue. These physiological signal techniques are often applied to clarify the differences in the movements of expert and novice athletes. Ishii [5] examined golf and found that numerous famous golfers believed that training necessitates repeated practice and understanding how to relax the muscles. The study observed that high-level players seldom had strain in their swing when they adjusted radians and striking angles, whereas novices frequently strained their muscles and injured themselves during practice. Biofeedback technology was also used to measure reflexes and attention on game design [6]. The most common EMG features are time-domain root-mean-square amplitude (RMS). RMS is increasing and accompanied with strong muscle contraction activity [7]. On the other hand, in the frequency domain feature, median frequency is often used to evaluate muscle fatigue. Median frequency will be decreasing as time increasing. People with high muscle

fatigue are accompanied with decreasing slope of median frequency [8].

RC racing is the operation of RC model cars. The global RC model market has an annual sales volume of approximately US 2 billion dollars. RC cars can perform driving techniques that actual race cars cannot accomplish. Thus, they have attracted interest from numerous people. Operators control the throttle by using their left hands, and the direction of the front of the cars is controlled using their right hands. Remote signals are used to control the vehicles [9]. Competition can be divided into two types: those in which cars compete to travel the farthest distance within a fixed amount of time and those in which cars compete to complete a fixed number of laps within the shortest period of time. Model cars are divided into four types: on-road, off-road, drifting, and rock-crawling cars. On-road cars were used in this study to determine the differences in the operation methods of expert and novice RC operators. High-speed RC cars move extremely quickly and demand rapid finger response capabilities to handle driving conditions. Attention is more critical issue for RC car racing. The RC car speed is up to 100 km/hour for expert RC operator. RC car operator must keep up with the car running, or will lose the control of car and lose the game. There are many methods to measure attention levels, one of the simple way is to measure eye-blinking number derived from Electrooculography (EOG)[10]. The eye-blinking number will be shorter when content player is more focus, and heart rate will be slower [11]. Muscle contraction, eye-blinking and heart rate are potential candidate to measure outstanding RC car operator performance. Even such a popular sports, there is neither study on this interesting issue. Goal of this study was propose a novel RC car motion learning level assessment approach. Finger muscle sEMG, Electrocardiography (ECG) signals, and eye blinking behavior were used as the basic signals to construct the measurement system.

## **Subject Information**

The recruitment conditions for the participants are discussed as follows: the expert group was comprised of operators who previously participated in large-scale domestic or overseas competition. Novice group was comprised of people with minimal contact with RC cars. The expert group consisted of 12 people (M:F=11:1) with an average age of  $35.07 \pm 9.06$  years (14~44 years) and a RC car operation experience of  $58.2 \pm 40.3$  months. The novice group consisted of 11 people (M:F=10:1) with an average age of  $30.45 \pm 8.44$  years (24~49 years) and an RC car operation experience of  $0.10 \pm 0.16$  months. Nearly all of the people in the novice group only recently learned RC racing. The participants were informed of the purposes of this experiment before recruitment and signed informed consent forms. All of the participants had adequate sleep the night before the experiment. Their physical conditions were normal on the day of the experiment. This experimental process was approved by the Asia University Medical Ethics Committee (Number 10207003).

## **Experiment design and procedure**

The participants provided relevant information and completed human experiment consent forms.

(i) A multifunctional physiological signal measurement system from iWorx equipped with an amplifier ETH 256 and 118 AD converter, computer, and video camera were set up. The positions for measuring the physiological signals of the participants are presented as follows: EMG—attached to the left index finger and the right thumb and right middle finger; EOG—attached to both the right and left sides of the eye area; and ECG—attached to the left and right hands. The data sampling frequency was 1 kHz: gain was 5, cutoff frequency of low pass was 50 Hz, and cutoff frequency of high pass was 0.03 Hz. The amplifier setting for the EMG was slightly different: hardware cutoff frequency ranged between 0.03 and 500 Hz.

(ii) When the recording of physiological signals began, the operation of the RC cars and the experimental process was explained to the participants. Whether the recorded physiological signals were abnormal was tested simultaneously.

(iii) The experimental site was a professional venue in Taipei, Taiwan. Vehicle movement was as shown in the video [12]. The venue had three track types, namely a hairpin corner, rag strip, and

S-bend tracks, which are respectively referred to as S1, S2, and S3 in the subsequent statistical analysis. The total lengths of the track was approximately 300 m. S1 was approximately 15 m, S2 was approximately 100 m, and S3 was approximately 100 m. The participants stood on the central grandstand and controlled the vehicles remotely while their physiological signals were measured.

(iv) Experimental Data Acquisition: Cameras were used to shoot the iWorx and vehicles. The physiological signal recording times were continuously synchronized with the video times. The frame rate of the video was 30 fps. Sync between the Video and Signal was adjusted with interpolation through linear regression to identify the time adjustment formula of linear regression from the videos and physiological signals. The RC cars were operated for nine laps. Figure 1 shows the complete experimental process.

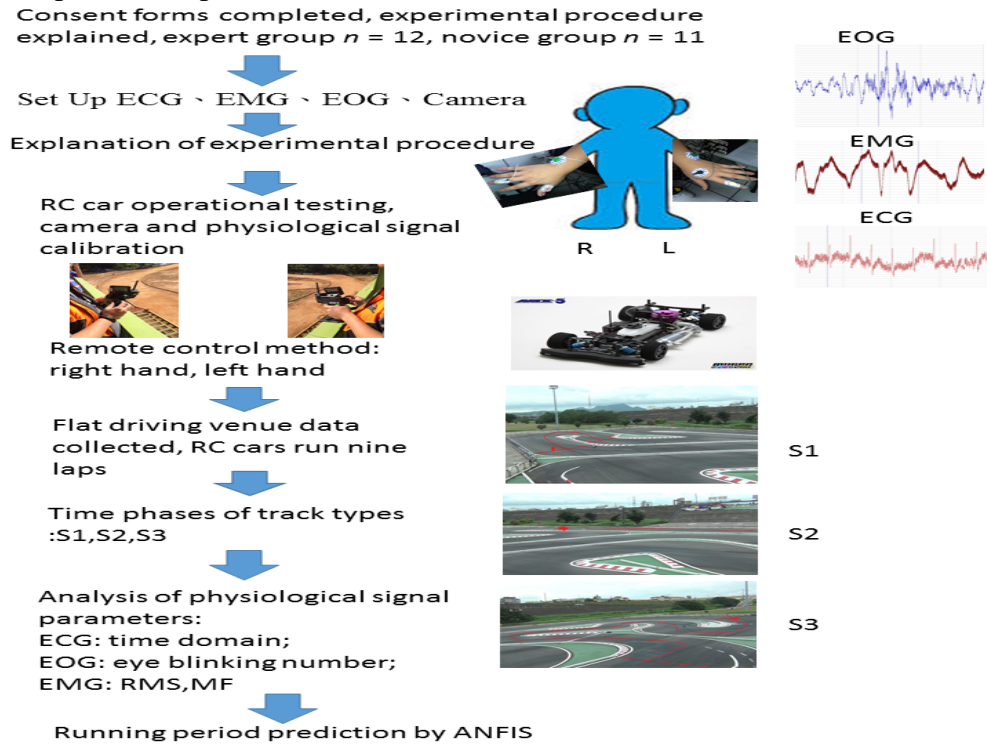


Fig.1. The complete experimental procedure.

### Signal Analysis

(i) ECG: The heartbeat can be used to reflect autonomic functions, stress, anxiety, and relaxation. In this experiment, the Tompkins algorithm was applied as a foundation to calculate and record the RR-interval signals captured using the ECG monitors. Because the time recorded to monitor the nine laps performed by the expert group was less than 5 min in length, the subsequent ECG parameters were based on the heart rate variability (HRV) time-domain parameter. These values were calculated as follows:

Mean<sub>RR</sub>: means RR interval.

$$\text{Mean} = \frac{\sum_{i=1}^n \Delta RR_i}{n} \tag{1}$$

Where  $\Delta RR_i = RR_{i+1} - RR_i$

SDNN: standard derivation of all RR intervals.

$$SDSD = \sqrt{\frac{1}{N} \sum_{i=1}^N (\Delta R_i - \overline{\Delta RR_i})^2} \tag{2}$$

SDSD: standard deviation of differences between adjacent RR intervals.

$$SDNN = \sqrt{\frac{\sum_{i=1}^N (RR_i - \overline{\Delta RR_i})^2}{N}} \tag{3}$$

Window length is dynamic and equal to the rap time length of each circle on S1, S2 and S3 pattern.

(ii) EOG: The method adopted for focus was eye blinking. Although numerous indicators for focus exist, to measure the degree of dynamic focus of the operators when operating the RC cars, eye blinking was used as a feature. The eye blinking number was estimated from the EOG data by visual examination with several experts.

(iii) EMG: The root mean square (RMS) of the EMG signal amplitude, and median frequency (MF) of the EMG spectrum were used as EMG parameters.

① RMS:  $x[n]$  is the raw EMG signal sequence,

$$x1[n] = x[n].^2 \tag{4}$$

$$x2 = \text{smooth}(x1, 25) \tag{5}$$

$$x3 = \text{sqrt}(x2) \tag{6}$$

$$\text{RMS} = \max(x3) \tag{7}$$

② MF: The MF is defined as the following:  $p(f)$  is power spectrum of the EMG signal  $x[n]$ , and

$$\int_0^{MF} p(f)df = \int_{MF}^{\infty} p(f)df = \frac{1}{2} \int_0^{\infty} p(f)df \tag{8}$$

Raw Data  $x[n]$  is extracted with Hamming window, and window length is also dynamic and equal to the rap time length of each circle on S1, S2 and S3 pattern, the same with ECG signal analysis window length.

### Statistics

In this experiment, t-test were used in the following areas: rap times for nine laps, S1, S2, and S3 of the expert and novice. EMG, ECG, and EOG features compare of the expert and novice groups on the three track types.

### Results and Discussion

Table 1 presents the time of nine laps and individual S1, S2, and S3 sections. The average time of the expert group was 206 seconds (speeds: 47 km/hour), and the average time of the novice group was 413 seconds (speeds: 24 km/hour). Statistically, the speed at which the expert group operated the RC cars was faster than that at which the novice group did. Both groups had the slowest speeds on S1. Their speeds were 19 km/hour and 14 km/hour. This type of turn has the slowest turning speed of all types of bend. The two groups were fastest during the nine laps on S2, reaching average time of 23 seconds (speeds: 129 km/hour), and 51 seconds (speeds: 71 km/hour) respectively, which was the largest difference in time between the two groups among the three track types. The expert group reported that S2 was the most favorable segment for reducing gaps with competitors and shaving off seconds. They drove on this track at full speed. By contrast, because the novice group feared that driving exceedingly fast would make controlling the cars difficult. On S3, the average speeds were 53 km/hour and 47 km/hour for two groups.

Table.1. Rap time for running nine circles and different tracks in two groups.

	Time (second)			Speed (km/hour)		
	Experts	Novices	P value	Experts	Novices	P value
ALL	206.6 ± 14.3	413.6 ± 78.6	<0.001***	47.1 ± 3.2	24.2 ± 4.3	<0.001***
S1	24.6 ± 1.9	35.7 ± 6.8	<0.001***	19.7 ± 1.6	14.1 ± 2.7	<0.001***
S2	23.3 ± 1.3	51.8 ± 21.0	<0.001***	129.2 ± 7.6	71.4 ± 26.1	<0.001***
S3	60.4 ± 3.7	69.3 ± 6.7	0.001**	53.4 ± 3.5	47.5 ± 6.4	0.001**

mean± SD; \*\*: p<0.005; \*\*\*: p<0.001.

Regarding the ECG signals, the time-domain parameters captured using HRV analysis were Mean\_RR, SDNN, and SDSD, as shown in Table 2. The two groups had statistically significant differences in all of these parameters (p < .05\*). Mean\_RR indicated that the heartbeat interval of the expert group was longer than that of the novice group, suggesting that when enduring the stress of this type of competition for an extended time, the expert group could adjust its own stress levels,

and were highly focused on controlling the RC cars. Increased focus on one objective stabilizes and moderates the heartbeat. By contrast, the novice group had minimal prior experience with this type of sport. With regard to their ECG during the experiment, their heartbeats accelerated and their conditions displayed tension. Eye blinking rate is listed in Table 3. The blinking rate of the expert group was  $0.79 \pm 0.65$  (times/min), indicating that the expert group was extremely focused on controlling the RC cars. Comparatively, the average number of times that the novice group blinked was  $1.84 \pm 0.63$  (times/min). In particular, the expert group had nine participants exhibiting blinking rate less than 1.1 (times/min), whereas the lowest blinking rate in the novice group was 1.16 (times/min). These results indicated that the novice group did not focus on the RC cars as attentively as the expert group did. They were easier to lose focus. Thus, numbers of operating mistake were clearly higher than the expert group. Table 4 presents EMG features of the left and right hands according to three tracks. The data indicated that, except for the RMS of the right hand for S3, the other EMG's RMS and MF were effective for distinguishing between the expert and novice groups.

Table.2. HRV analysis of the ECG signals in two groups. (unit is ms).

ECG-HRV	Experts	Novices	P value
Mean_RR	738.95 ± 26.63	680.50 ± 61.4	0.005**
SDNN	236.06 ± 18.18	187.27 ± 59.15	0.01*
SDDSD	360.67 ± 30.48	273.95 ± 95.87	0.005**

mean ± SD; \*: p<0.05, \*\*: p<0.005.

Table.3. Eye blinking rate distributions in two groups. (unit is number/minute, p value =0.0006\*\*\*)

Eye Blinking rate group	Experts	Novices
0 – 1.1	9	0
1.1– 1.9	3	7
> 1.9	0	4
Mean(SD)	0.73 ± 0.65	1.84 ± 0.63 ***

Table.4. The RMS and MF of EMG of right and left hands for different tracks in two groups.

EMG	Feature	Experts	Novices	P value
Left Hand/S1	RMS	3.74 ± 1.06	2.70 ± 0.52	<0.001***
	MF	183.64 ± 42.22	220.34 ± 19.87	<0.001***
Left Hand /S2	RMS	3.06 ± 0.90	2.81 ± 0.73	0.02*
	MF	190.22 ± 47.7	223.44 ± 18.93	<0.001***
Left Hand /S3	RMS	4.32 ± 1.02	2.90 ± 0.65	<0.001***
	MF	167.49 ± 34.39	221.83 ± 18.71	<0.001***
Right Hand/S1	RMS	4.36 ± 1.52	3.92 ± 0.86	0.01*
	MF	161.3 ± 34.11	213.1 ± 22.26	<0.001***
Right Hand/S2	RMS	4.17 ± 1.48	3.76 ± 0.83	0.02*
	MF	168.27 ± 35.98	215.39 ± 21.36	<0.001***
Right Hand/S3	RMS	4.49 ± 1.39	4.35 ± 1.16	0.42
	MF	166.37 ± 30.72	216.98 ± 22.37	<0.001***

(unit: RMS is 100 mV MF is Hz)

This study was the first to apply physiological signals to observe the reactions of RC car operators in an academic journal. The application of physiological signals must be matched with an appropriate environment. The RC car operators stood fixed on a grandstand and looked downward at their RC cars. They used their left hands to control the throttle and their right hands to control the direction of their wireless RC cars. Similar to other sports, RC racing requires a high focus. This focus was also reflected in the heartbeat rate and blinking rate. For example, the heart rates of exceptional archers tend to slow before releasing their arrows [13]. Regarding EOG signals, people blink less frequently when focusing on an objective than when not focusing on objectives. This study obtained similar results. The expert group had a low blinking rate, slow heartbeats, and high SDDSD. EMG signals can be used to monitor hand muscle activity effectively. In particular, in RC car operators, the primary activities are finger and wrist movements. The time domain EMG feature, RMS, was a good feature to distinguish the operation difference between the expert and novice groups. The operation stability of the expert group is higher than the novice group.

## Conclusion

EMG, ECG, and EOG signals from the fingers of both hands were used to establish a system for assessing RC car operators. The operating techniques of an expert group in throttle operations and maintaining the turning stability of RC cars were measured. The differences in focus and stress between the expert and novice groups were determined using EOG and ECG data. This measurement system can provide effective assistance in the future establishment of training systems and plans for RC car operators.

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