# Noise Assessment during Motor Race Events: New Approach and Innovative Indicators

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*Abstract:* - Motorsport races significantly affect, on a local scale, noise pollution even if they do not represent the majority of its contribution, which is a prerogative of road transportation, railways, airports, and industries. Nevertheless, such noise emissions surely affect the well-being of inhabitants in the surrounding area of the circuit. In fact, during a motor race event, vehicles produce high noise emissions while on tests, qualifying, and race sessions. Since noise indicators commonly used in national regulations are computed over fixed times, it is challenging to properly assess the total noise emission and immission at the receivers during such events. Moreover, in literature, only a few works can be found assessing this specific issue, and consequently, there's also a lack of appropriate methods to properly measure the global noise emission of each event. In this contribution, the authors report the characterization of noise emission during motor race events by using two new acoustic indicators, namely LEL (Lap Equivalent Level) and REL (Race Equivalent Level) starting from noise data collected on different points along a racing circuit. Measurements show that the REL tends to stabilize its value during a race, suggesting that its modelling can be achieved only based on the average LEL and the number of vehicles participating in a race. These indicators will allow predicting the total noise emission at a certain receiver of a motor race event by knowing the number and type of cars involved, without using the duration of the race itself.

*Key-Words:* - Acoustics, Noise Control, Noise Emission, Motor Race Events, Modelling and Simulation

Received: December 9, 2022. Accepted: January 5, 2023. Published: January 31, 2023.

## 1 Introduction

Among all the pollutants daily threatening human health, noise is one of the most relevant. In urban areas, the primary contribution to noise level comes from transportation (road, railway, and aircraft), and the effects on human beings are widely studied and documented, [1]. For instance, the sleep quality of people exposed to constant high-level traffic noise could be compromised, leading to potential short-term (tiredness, lack of concentration) and long-term (chronic hypertension) consequences, [2], [3], [4], [5], [6], [7], [8], [9], [10], [11]. Several studies can be found in the literature assessing and modelling road traffic noise emissions and propagation (see for instance [12], [13], [14], [15]). On the other hand, sports cars' noise emissions (during motor race events) have peculiar aspects that need to be deeper investigated. These events are characterized by large sound pressure levels produced by sports cars, which usually do not embed mufflers and are not required to respect the noise emission limit of the passenger cars. Due to the number of homologated tracks present on the Italian territory (18 racetracks, 17 kart tracks, and 10 mini tracks, a total of 45), it appears clear that the number of people exposed to these particular noise emissions is not negligible, not only in terms of spectators and workers but also citizens living nearby, [16]. Since specific scientific papers are not many in the literature, more and deeper investigations could be useful. [17], as an example, in a whole study of the effects of motor race events in Australia also consider noise pollution but the approach is generalist and not focused on the noise emission problem. [19], collected noise data during the Formula 1 Gran Prix of Canada in 2013; the recorded noise levels reached a threshold that suggested wearing appropriate protections. In this case, common A-weighted continuous equivalent levels ($L_{eq,A}$) are used to assess the noise emitted from the racing cars, applying it to the time of measurement. Other subsequent works have focused on noise emissions during a car race, [19], [20], [21], [22], but still, no new and dedicated indicators are presented. The lack of specific regulation for noise emission reflects on the missing indications for such noise assessment, thus general national regulations for circuits functioning are applied. Commonly adopted indicators are computed over fixed times, without any assessment of the particular race. Thus, the used indicators are not perfectly suitable to determine the noise emitted from races, typically with variable time length.

To fill this gap, in this contribution, the authors report the new approach presented in, [23], to deepen the characterization of noise emissions during motor race events by introducing two new acoustic indicators, namely LEL (Lap Equivalent Level) and REL (Race Equivalent Level). These indicators will allow predicting the total noise emission at a certain receiver of a motor race event by knowing the number and type of cars involved.

## 2 Methodology

The computation of specific indicators, able to assess the noise levels produced in motorsport events at a certain receiver point, is needed, due to the particular nature of the events themselves. The most used indicator in literature and many regulations is the equivalent continuous A-weighted sound pressure level – $L_{eq,A}$. It is an energetic parameter that provides a very useful description of fluctuating (time-varying) sound levels. It is expressed as in equation (1):

$$L_{eq,A} = 10\log_{10}\left(\frac{1}{T}\int_0^T \frac{p_A^2}{p_0^2}dt\right) \quad (1)$$

where $T$ stands for the time interval of interest, usually fixed by regulation or by measurement duration, $p_A$ is the A-weighted sound pressure in Pascal and $p_0$ is the reference sound pressure equal to $2 \cdot 10^{-5}$ Pa. The $L_{eq,A}$ gives a single value in dB(A) that takes into account the total sound energy over the entire time period of interest. Starting from this indicator, the research was mainly focused on the definition of two new acoustic indicators: the Lap Equivalent Level (LEL) and the Race Equivalent Level (REL). They modify the measurement times of the equivalent continuous sound level, best applying to the contest of a motor race events, where the time span of the emitted sound depends on the whole race which, in turn, depends on how many times the cars are turning the whole circuit.

Indeed, the LEL can be defined as the equivalent continuous sound level immitted at a certain receiver by a single vehicle in one lap of the track. The mathematical formulation of LEL is reported in equation (2):

$$LEL = 10\log_{10}\left(\frac{1}{t_{lap}}\int_0^{t_{lap}} \frac{p_A^2}{p_0^2}dt\right) = = 10\log_{10}\left(\frac{1}{t_{lap}}\int_0^{t_{lap}} 10^{\frac{Lp(t)}{10}}dt\right) \quad (2)$$

where, $t_{lap}$ is the time, expressed in seconds, that a vehicle needs to perform a single lap of the track.

Similarly, the REL can be defined in equation (3) as the equivalent continuous sound level immitted at a certain receiver during a race by all the vehicles running on the track:

$$REL = 10\log_{10}\left(\frac{1}{t_{race}}\int_0^{t_{race}} \frac{p_A^2}{p_0^2}dt\right) = = 10\log_{10}\left(\frac{1}{t_{race}}\int_0^{t_{race}} 10^{\frac{Lp(t)}{10}}dt\right) \quad (3)$$

where $t_{race}$ is the entire duration of the race expressed in seconds.

Although both are defined as equivalent sound levels, they are characterised by being calculated over a variable time interval (lap and race time respectively) rather than a fixed one. This approach makes it possible to assess the noise emitted by an individual car during a track lap (in the case of LEL) and the group of cars during a race (in the case of REL). Therefore, LEL and REL are indicators that aim to assess the noise immitted at the receivers rather than to assess exposure. For the latter, however, fixed reference times must be considered.

In this paper, the authors apply the LEL and REL approach both to a single-vehicle track test and different race sessions, to describe the potentialities of the method and to demonstrate its validity and robustness. A more detailed description of the applications is reported in [23].

## 3 Case Study Description

The circuit selected as a case study to test the above-presented indicators is the "Circuito del Sele" located in the city of Battipaglia, Italy. Battipaglia is situated on the northern edge of the Sele plain, in the district of Salerno and its territory is mainly hillside. The circuit hosts all kinds of motor events, such as car races, super motard races, scooter races, kart races, and safe driving courses. The track has a total length of 1.69 km and the pit straight is approximately 400 m long. It is one of the largest circuits in southern Italy. The route is almost flat and only in some sections, it presents a slope that reaches about 1-2%. It should be emphasized that the road pavement is different from the ones used in civil applications since it must fulfill the requirements of the sports federations' regulations. In this case, it is made of 6 cm-thick circuit-draining asphalt, which is highly porous and draining.

Figure 1 and Figure 2 show the geographical position within the Campania region, as well as the track layout, with the points selected for the measurements (A, B, C). The technical details of the circuit are given in Table 1.

A Class 1 sound level meter (FUSION) was placed at point A (see Figure 2), about 7.5 m away from the central axis of the pit straight, during a single vehicle test session. The sound level meter was opportunely calibrated with a reference signal of 94 dB at 1000 Hz. Sound pressure level – $L_p$ was measured every 100ms, while a Formula X category vehicle was running on the circuit. The vehicle was a single-seater car, equipped with a 1.6 L engine, with 16 valves. Further noise data were collected during a competition event consisting of several race sessions, at two different locations, referred to as points B (at the border of the track) and C (out of the track), as shown in Figure 2, using two Class 1 sound level meters (respectively Panasonic Soundbook MK2 and FUSION). These two points are placed at a turn situated about 15 and 30 m from the roadway respectively. Figures 3 and 4 offer a different point of view of the Sound Level Meters positions in points A and B. It is also important to emphasize that the equipment was properly calibrated, and their clocks were synchronized before the measuring campaigns.

Fig. 1: Map of the circuit location.


Fig. 2: Track layout with indications about measurement point's position.

Fig. 3: Sound Level Meter position at point A during the single vehicle test.

Fig. 4: Sound Level Meter position at point B during the race sessions.

Table 1. Technical details of the circuit as a kart track.

| Technical features | Kart track | Mini-car track |
|---|---|---|
| Length [m] | 1345 | 1800 |
| Max. width [m] | 11 | 13 |
| Min. width [m] | 8 | 9 |
| Pit straight length [m] | - | ~400 |
| Direction of travel | Clockwise | Clockwise |
| Slope | 2-3% | 2-3% |
| Roadway width [m] | 10 | 10 |

## 4 Results and Discussion

The recorded noise signal during the single-vehicle test session of the Formula X car is reported in Figure 5, where values of $L_p$[dB(A)] are plotted against time, with a temporal resolution of 100 ms.

The vehicle drove around the circuit for a total of 17 laps. The graph clearly shows a peculiar trend, with peaks (>100dB(A)) periodically repeating through time. Such peaks occurred when the car passed in the proximity of the receiver. Based on the $L_p$ values measured, the LEL values were determined using equation 2. Since the lap race is approximately constant through the progress of the race itself, it makes sense to compare the distance between peaks and the lap time. Thus, the lap times were estimated by calculating the temporal distance between the peaks recorded in the noise signal during the test. De facto, comparing the lap time estimations with the information retrieved from the telemetry system, we found a very sharp correlation: the time distance between each peak corresponds to a lap time. The maximum absolute difference between lap time estimations and lap time values from telemetry is 0.4 seconds which is no bigger than 0.49%. All the results of this measurement campaign, in terms of lap time estimation and measurement, absolute errors, and LEL values are reported in Table 2, with the total average and standard deviation of each column. Table 3 shows recorded values of REL during the race sessions, respectively for point B and point C. Each row refers to a category of the competition event.

From a theoretical point of view, fixed all the possible boundary conditions, given two receivers (as in the case reported in Table 3), it is expected to have a higher noise emission at the receiver that is nearer to the carriageway. However, in the presented case, REL values are generally higher at receiver C than at receiver B even though it was positioned at 30 meters from the carriageway while receiver B was at 15 meters (see Figure 4). This can be due to the fact that REL values depend on many factors such as source-receiver distance, type of vehicle, number of vehicles, speed of vehicles, drivers' behavior, and engine revolution per minute (engaged gear).

Table 2. Single-vehicle test noise output.

| Lap | Lap Time estimation [s] | Lap time from telemetry [s] | Time-lap absolute error [s] | *LEL* [dB(A)] |
|---|---|---|---|---|
| 1 | 82.0 | 82.4 | 0.4 | 86.2 |
| 2 | 76.5 | 76.3 | 0.2 | 87.1 |
| 3 | 73.2 | 73.2 | 0.0 | 86.1 |
| 4 | 71.9 | 71.6 | 0.3 | 85.8 |
| 5 | 74.1 | 74.4 | 0.3 | 84.6 |
| 6 | 71.3 | 71.4 | 0.1 | 84.7 |
| 7 | 70.4 | 70.3 | 0.1 | 84.7 |
| 8 | 69.9 | 70.0 | 0.0 | 84.0 |
| 9 | 68.9 | 68.9 | 0.0 | 85.2 |
| 10 | 69.7 | 69.6 | 0.1 | 85.1 |
| 11 | 69.3 | 69.3 | 0.0 | 85.0 |
| 12 | 67.7 | 67.8 | 0.1 | 84.7 |
| 13 | 69.6 | 69.5 | 0.1 | 84.5 |
| 14 | 69.3 | 69.2 | 0.1 | 84.6 |
| 15 | 68.2 | 68.5 | 0.3 | 84.3 |
| 16 | 69.0 | 69.0 | 0.0 | 84.6 |
| 17 | 69.5 | 69.5 | 0.0 | 83.9 |
| Average | 71.2 | 71.2 | 0.1 | 85.0 |
| St. Dev. | 3.6 | 3.6 | 0.1 | 0.9 |

Table 3. REL measured in points B and C during races and the time of each race.

| Race category | $REL_B$ [dB(A)] | $REL_C$ [dB(A)] | $t_{race}$ [s] | *Number of cars* |
|---|---|---|---|---|
| Assominicar1 | 84.4 | 86.3 | 963 | 12 |
| Assominicar2 | 88.2 | 89.5 | 1014 | 8 |
| N 1400 | 83.3 | 79.3 | 401 | 6 |
| N 1600 | 85.0 | 81.4 | 401 | 8 |
| Gr. 5700 | 86.3 | 87.0 | 408 | 6 |
| GT CUP' | 87.6 | 89.8 | 232 | 6 |
| GT CUP'' | 85.4 | 86.8 | 357 | 4 |
| Single-seater | 89.0 | 90.9 | 352 | 4 |

N.B.: GT CUP' and GT CUP'' are related respectively to the GT CUP race before and after the red flag.

Source-receiver distance is the easiest contribution to be explained: the greater the distance the lower the recorded emission levels. Hence, the choice of the receiver position is crucial for a correct evaluation of LEL and REL.

It also has to be taken into account that various types of vehicles, having diverse kinds of engines, mufflers, and insulation, correspond to different noise emission levels. In the case analyzed in this work, there are vehicles obtained from historic twin-cylinder-engine cars, with free exhaust pipes and series-derived cars, characterized by more efficient acoustic insulation of the engine.

Furthermore, as widely reported in the literature (see for instance, [24]), the high speed of vehicles correlates with high sound levels. Since REL is an equivalent sound level calculated over a race time interval, its value is dependent on speed as well. For the same reason, since each race can be characterized by a specific number of participating vehicles, it must be considered for the REL estimation.

Another crucial contribution is given by the drivers' behavior. For example, in the hypothesis that a driver maintains a slightly lower speed (as in the measuring point B of the studied circuit) by using the lowest gear, the engine revolution per minute increases. This leads to a higher sound power level of the engine source and, consequently, to higher REL (and vice versa).

Finally, a strategic position also makes a difference. As an example, REL and LEL values, recorded at receivers positioned on a straight part of the track, will be particularly high: in fact, vehicles pass at maximum (full) speed on rectilinear parts, generating high sound levels. On the opposite, vehicles' speed could be particularly low along chicanes and turns, and as a consequence of that, LEL and REL values could be lower at these receiver points.

All these parameters are interdependent: Table 3 focuses on the comparison between REL measured in points B and C during different races showing that the source-receiver distance is not always the predominant factor influencing noise levels, as would be expected. This is visible for "N1400" and "N1600" races.

Figure 6 shows $L_p$ recorded during the N 1600 race at points B and C, and the "running REL" curve, i.e. the integral shown in equation (3) calculated as a function of time, increasing the upper limit during the event. It must be stressed that running REL values are plotted at every tenth of a second (always considering the start of the race as the initial time for REL computations).

Peaks in $L_p$ curve, all around 95 dB(A), have to be related to the cars' passing in front of the two receivers. It is interesting to notice how REL value tends to stabilize after about two laps by the race starts (comparable values have been found for other races, data not shown). It can be empirically suggested, then, that running REL value, after stabilization, can be estimated through vehicle types and numbers, and position of the receivers, without using race time. The periodic pattern of the sound pressure level, due to the repetition of the laps, leads to a little influence of the overall $t_{race}$ on the running REL estimation (see also literature, [22], [25]).

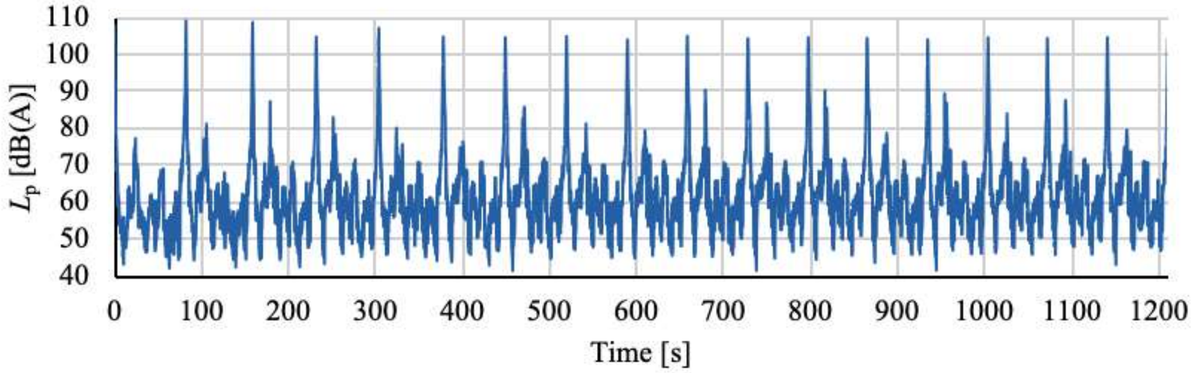


Fig. 5: Noise signal during a single vehicle track test.

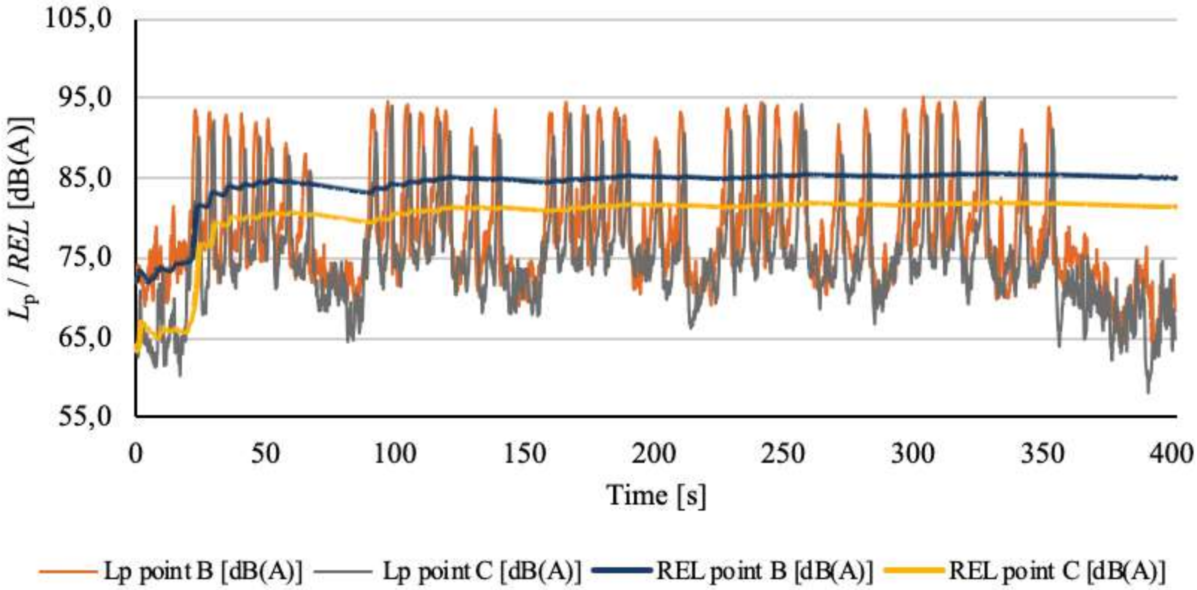


Fig. 6: Noise signal and running REL values for the N 1600 race at points B and C.

With such a consideration, the following equation is proposed to estimate REL value for a determined race as in, [23]:

$$REL = \overline{LEL} + 10\log_{10}(N) \quad (4)$$

by having the number of vehicles ($N$) and an average Lap Equivalent Level ($\overline{LEL}$) at a certain receiver. Another assumption is that vehicles participating in the race belong to the same category and have approximately the same noise emission level. LEL values are not available for the vehicles competing in the races and this prevents the estimation of REL through the above-mentioned equation. Nevertheless, during the GT CUP race, a red flag occurred, and the race restarted with two fewer vehicles: it was then possible to compute LEL by inverting equation (4) and knowing car numbers before and after the red flag, by the mean of the REL values at the two receivers, as in equation (5).

$$\begin{cases} \overline{LEL_B} = REL'_B - 10\log_{10}(N) \\ \overline{LEL_C} = REL'_C - 10\log_{10}(N) \end{cases} \quad (5)$$

In particular, considering that the REL' measured at point B and point C before the race was interrupted through the red flag is respectively 87.6 dB(A) and 89.8 dB(A) and that the number of sports cars initially present on the circuit are 6, $\overline{LEL}$ values can be obtained at the same points of 79.9 dB(A) and 82.0 dB(A).

This leads to the estimation of REL'' values as in the equations (6).

$$\begin{cases} \overline{REL''_B} = \overline{LEL_B} + 10\log_{10}(N) \\ \overline{REL''_C} = \overline{LEL_B} + 10\log_{10}(N) \end{cases} \quad (6)$$

In the analyzed case, taking into account the evaluated values of $LEL_B$ and $LEL_C$, and that the number of the participating cars decreased to 4 after the red flag, REL'' values at point B and point C were respectively 85.9 dB(A) and 88.0 dB(A).

It can be observed (see Table 3) as the values of REL in points B and C are overestimated by 0.5 dB(A) and 1.2 dB(A), which corresponds to 0.57% and 1.32%.

The graphical slopes of sound pressure level at the receivers B and C, and of the running REL values in the two points, measured during the GT CUP race, are reported in Figure 7 and Figure 8, respectively before and after the red flag.

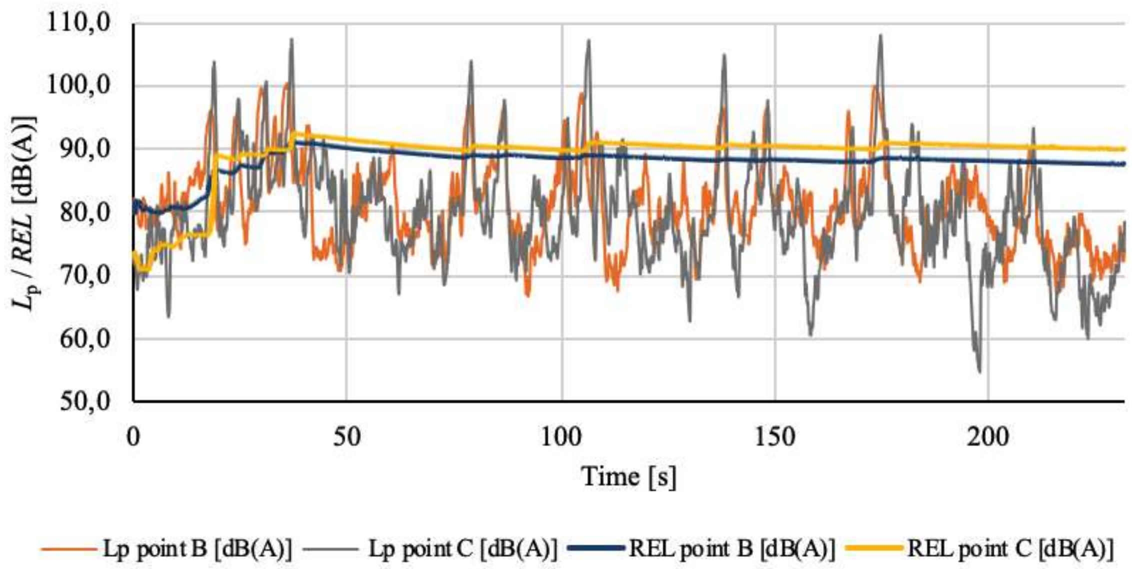


Fig. 7: Noise signal and running REL values for the GT CUP race (before the red flag) at points B and C.

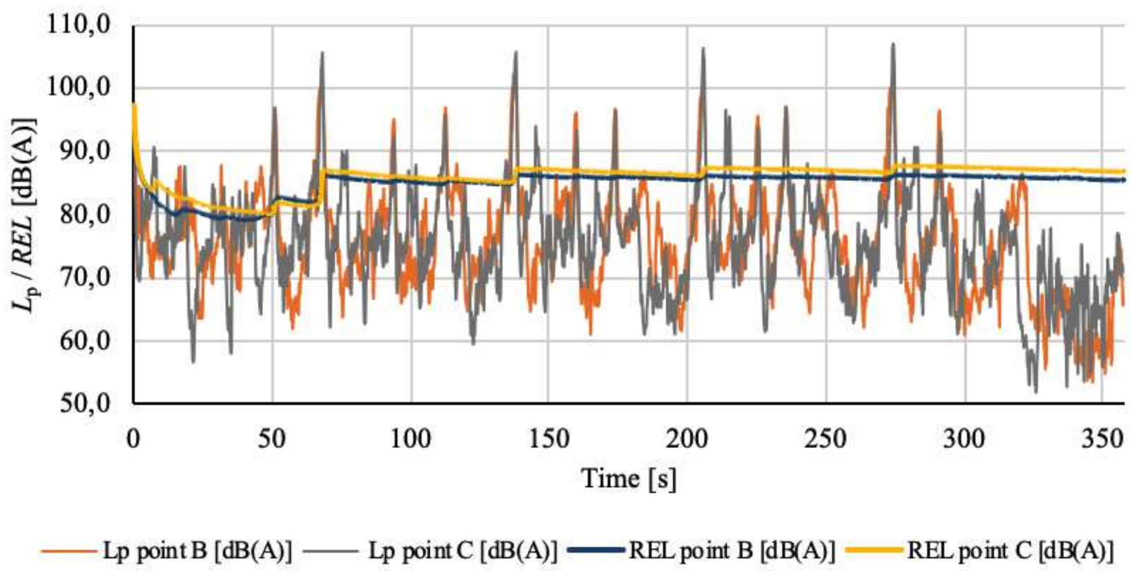


Fig. 8: Noise signal and running REL values for the GT CUP race (after the red flag) at points B and C.

# 5 Conclusions

In this work, the novel approach presented in, [23], aimed at assessing noise levels produced during motorsport events based on two innovative indicators, *LEL* and *REL*, was reported and validated in test and race sessions.

The methodology allows assessing noise levels produced during an event at any sensible receiver point and can be applied at any circuit layout, for any vehicle category, and for any time the race would last. Moreover, it must be highlighted that the novelty of this work is in the nature of the indicators. Both LEL and REL are defined as equivalent continuous A-weighted sound pressure levels that evaluate the acoustic energy of a single car during a lap and a bunch of vehicles during a race at a given receiver, respectively. However, the reference times (i.e., the lap time for LEL and the race time for REL) are not fixed. This leads to the advantage of comparing events characterized by a different duration and can overcome the lack of specific regulation for the assessment of noise emitted from a circuit during a specific race.

Future works will be aimed at generating the noise emission curves (sound power level – $L_w$ against speed) for different sports vehicles in order to feed the model and simulate several operating conditions of the tracks. From the telemetry information, the $L_w$ can be assessed at any position assumed by the vehicle on track, and therefore $L_p$ values at different receiver points can be easily obtained through a sound propagation model. The latter can be used to assess LEL and REL values. This procedure can be used to draw noise maps, both for existing and new infrastructures, in the area surrounding the circuit, with the advantage of separating the contribution of track operations from the other sources to the equivalent sound levels. In addition, these innovative indicators can provide new insights for the development of regulations for environmental assessment and protection, being more oriented at the real noise immitted by the circuits in the surroundings and being thus more effective for the estimation of the annoyance and the risk for human health.

# Acknowledgement:

This work has been presented at the ENCEMA2022 conference and an extended version of this paper can be found in, [23].
Authors deeply thank the Automobile Club Salerno for supporting this work within the agreement with the Department of Civil Engineering, University of Salerno. The authors are also grateful to the owners of the “Circuito del Sele” in Battipaglia, in particular to Nicola Rinaldi, for the availability and support during the measurements collection. Finally, the authors thank all the students participating in the measurements, in particular Paola Barra, for the efforts pursued during her master's thesis work.

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## Sources of Funding for Research Presented in a Scientific Article or Scientific Article Itself

A. Pascale and M. C. Coelho acknowledge the support of the following projects: UIDB/00481/2020, UIDP/00481/2020 – FCT, and CENTRO-01-0145-FEDER-022083. A. Pascale acknowledges the support of FCT for the Scholarship 2020.05106.BD.

## Conflict of Interest

The authors have no conflicts of interest to declare that are relevant to the content of this article.