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Ergonomic Study regarding the Effects of the Inertia and Centrifugal Forces on the Driver

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Abstract. The purpose of this paper is to observe the ergonomic advantages of different car seats and how the driver is constrained to them during the drive. The study was conducted by taking in to consideration the dynamical characteristics of a standard vehicle and subjecting the human body model provided by the AnyBody Modelling System, to inertia and centrifugal forces, in three different driving posture cases. The model proved to be viable and offered an image of different car seats advantages from ergonomic point of view.

Introduction

The influence of inertia and centrifugal forces on the human body during the drive shows a distinctive importance because it inflicts a state of tiredness, especially to the driver who makes an additional effort in comparison the other passengers.

Different forces and vibrations are transmitted to the human body through the car seat, through the vehicle chassis and through the surrounding air that can be applied on one or more directions.

The main effort results from centrifugal forces creating a postural stress, the effort made during the operation of different commands and the steering wheel, effort made for maintaining the balance in the seat while driving on uphill or downhill or following the road where the vehicle is driven.

Vehicle designers all around the world are trying to create functional seats that provide adequate physiological driving conditions. The creation of ideal driving condition implies a determination of the drivers efforts, their measuring and the response of the human body to each of these efforts, their comparison to normal physiological limits and as a result of this, the interventions on the driver's seat for setting the driver's demand to his physiological possibilities [3, 4, 5, 6].

The spine and internal organs are subjected to successive compressions and expansions. These unwanted movements produce on intervertebral disc side-compaction, a torsion of the spine, leading to neuralgias, sciatica, disc ruptures etc.

Due to the presence of soft tissues, of bones, of internal organs and also because of the configurationally particularities, the human body is a complex mechanical system. External forces can be transmitted to the human body in vertical, horizontal, sitting positions or through the hands while driving. The ways of transmitting these forces through the human body and the influence that they have on internal organs and tissues are of particular importance [1, 7, 9].

The vehicle dynamics

To determine the forces that act on the driver or on the passengers, during the drive, it is necessary first to determine the vehicle dynamic characteristics. Therefore in this study it is considered a passenger car with the next characteristics, extracted from the vehicle's technical book:

The cylinder capacity	$V_c = 1995$ [cm^3]
Maximum power	$P_{max} = 105$ [kW]
Maximum torque	$M_{max} = 190$ [Nm]
Revolutions at maximum power	$n_P = 6000$ [rev/min]
Revolutions at maximum torque	$n_M = 4250$ [rev/min]
Gearbox type	5 speed manual
Central transmission ratio	$i_0 = 4.5$
	$i_1 = 4.32$
	$i_2 = 2.46$
Transmission ratios of the gearbox	$i_3 = 1.66$
	$i_4 = 1.03$
	$i_5 = 0.85$
	L = 4.25 [m]
Gauge dimensions	B = 2.013 [m]
	H = 1.421[m]
Wheelbase	Am = 2.76 [m]
Axle track	Ec = 1.5 [m]
Tire type	255/55 R16 H
Own mass	Ga = 1435 [kg]
Maximum speed	$Va_{max} = 210$ [km/h]
Payload	Q_u=475 [kg]
Average consumption	$C_{med} = 5.9$ [l/100km]

The engine external characteristics. The first step to determine the vehicle's dynamic characteristics is to determine the power (Eq. 1) and torque (Eq. 2) for the whole engine functional range of revolutions [2].

$$P(n) = \frac{M(n)\cdot n}{9554}. \tag{1}$$

$$M(n) = M_{max} - \frac{M_{max}-M_P}{(n_P-n_M)^2}\cdot(n-n_M)^2. \tag{2}$$

The engine functional range of revolutions is given by $n = n_{min}, n_{min} + 47.75 \ldots n_{max}$, where $n_{min} = 0{,}5\cdot n_P$; $n_{max} = n_P + \frac{7}{100}\cdot n_P$ and $M_P = \frac{9{,}554\cdot P_{max}\cdot 10^3}{n_P}$.

Traction characteristic. The traction characteristic of the vehicle represents the tangential forces at the traction wheels (Eq. 3), the vehicle's speed (Eq. 4), and the aerodynamic factor (Eq. 5), for each gear [2].

$$F_R(n) = \begin{pmatrix} \frac{M(n)\cdot i_0\cdot i_1\cdot \eta_{tr}}{r_r} \\ \frac{M(n)\cdot i_0\cdot i_2\cdot \eta_{tr}}{r_r} \\ \frac{M(n)\cdot i_0\cdot i_3\cdot \eta_{tr}}{r_r} \\ \frac{M(n)\cdot i_0\cdot i_4\cdot \eta_{tr}}{r_r} \\ \frac{M(n)\cdot i_0\cdot i_5\cdot \eta_{tr}}{r_r} \end{pmatrix}. \tag{3}$$

$$V_a(n) = \begin{pmatrix} 0{,}377 \cdot \frac{r_r \cdot n}{i_0 \cdot i_1} \\ 0{,}377 \cdot \frac{r_r \cdot n}{i_0 \cdot i_2} \\ 0{,}377 \cdot \frac{r_r \cdot n}{i_0 \cdot i_3} \\ 0{,}377 \cdot \frac{r_r \cdot n}{i_0 \cdot i_4} \\ 0{,}377 \cdot \frac{r_r \cdot n}{i_0 \cdot i_5} \end{pmatrix}. \quad (4)$$

$$C_x = \frac{26}{\rho \cdot A \cdot V_{a\,max}} \cdot (F_R - f \cdot G_a). \quad (5)$$

Where:

- η_{tr} is the transmission total efficiency and it is considered to be 92%;
- r_r is the rolling radius of the wheels;
- ρ is the air density 1.226 [kg/m^3];
- A is the vehicle transverse area;
- f is the rolling resistance coefficient and it is considered to be 0.02 for asphalt;
- G_a is the total weight of the vehicle.

A distinctive importance for the traction characteristic of the vehicle, is the air resistance force (Eq. 6) and the rolling resistance force (Eq. 7). The air resistance force is determined in the range of top speeds, in which case the force action is more pronounced [2].

$$F_a(n) = \frac{1}{2} \cdot C_x \cdot \rho \cdot A \cdot \frac{[V_a(n)_5]^2}{13} \quad (6)$$

$$F_r = G_a \cdot f \quad (7)$$

At this phase the vehicle's most important dynamic characteristics are determined. To have a clear view of how the traction force vary depending on the vehicle speed in each gear, and how the drag forces act on the dynamics, a graphical representation is made in Fig. 1.

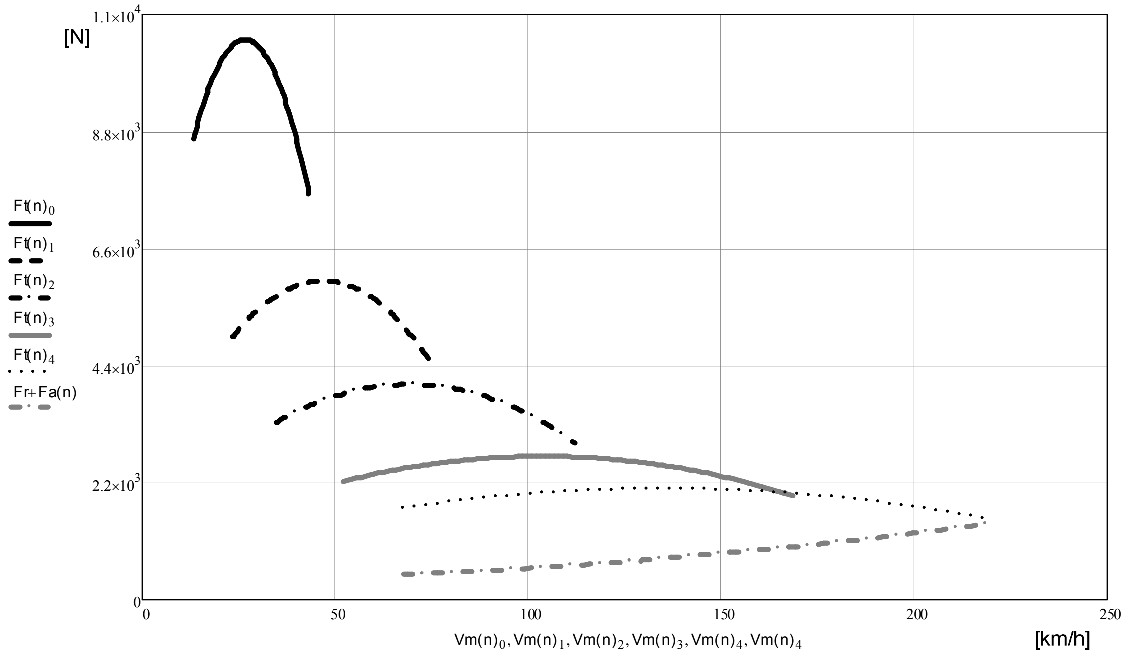

Fig. 1. The tangential forces in each gear and the drag forces in the range of top speeds.

It is very important to mention that the vehicle is driven on a road with 0% declivity.

The vehicle's acceleration. The last dynamic characteristic in this study is the vehicle's acceleration (Eq. 8).

$$a = \frac{dv}{dt} = (D - \Psi) \cdot \frac{g}{\delta_i} \quad (8)$$

$$D = \frac{F_R - F_a}{G_a} = f \cdot \cos\alpha + \sin\alpha + \frac{\delta_i}{g} \cdot \frac{dv}{dt} \cong \Psi + \frac{\delta_i}{g} \cdot \frac{dv}{dt} \quad (9)$$

Eq. 9 represents the dynamic factor, where:

- α is the road declivity considered to be 0º;
- $\Psi = f \cdot cos\,\alpha + sin\,\alpha$ is the movement resistance coefficient;
- $\delta_i = 1 + \lambda_i + \xi$ is the influence coefficient of the vehicle's rotating masses over the translation masses;
- $\lambda_i = \frac{J_m \cdot \eta_{tr} \cdot (i_0 \cdot i_{1..5})^2}{m_a \cdot r_r^2}$, where:
  - J_m is the inertia moment of the engine mechanism;
  - $m_a = \frac{G_a}{g}$ is the vehicle mass;
- $\xi = \frac{\sum_1^{nt} J_R}{m_a \cdot r_r^2}$, where:
  - J_R is the inertia moment of one wheel;
  - nt is the number of wheels.

The acceleration of the vehicle for each gear speed range is represented in graphical mode in Fig. 2.

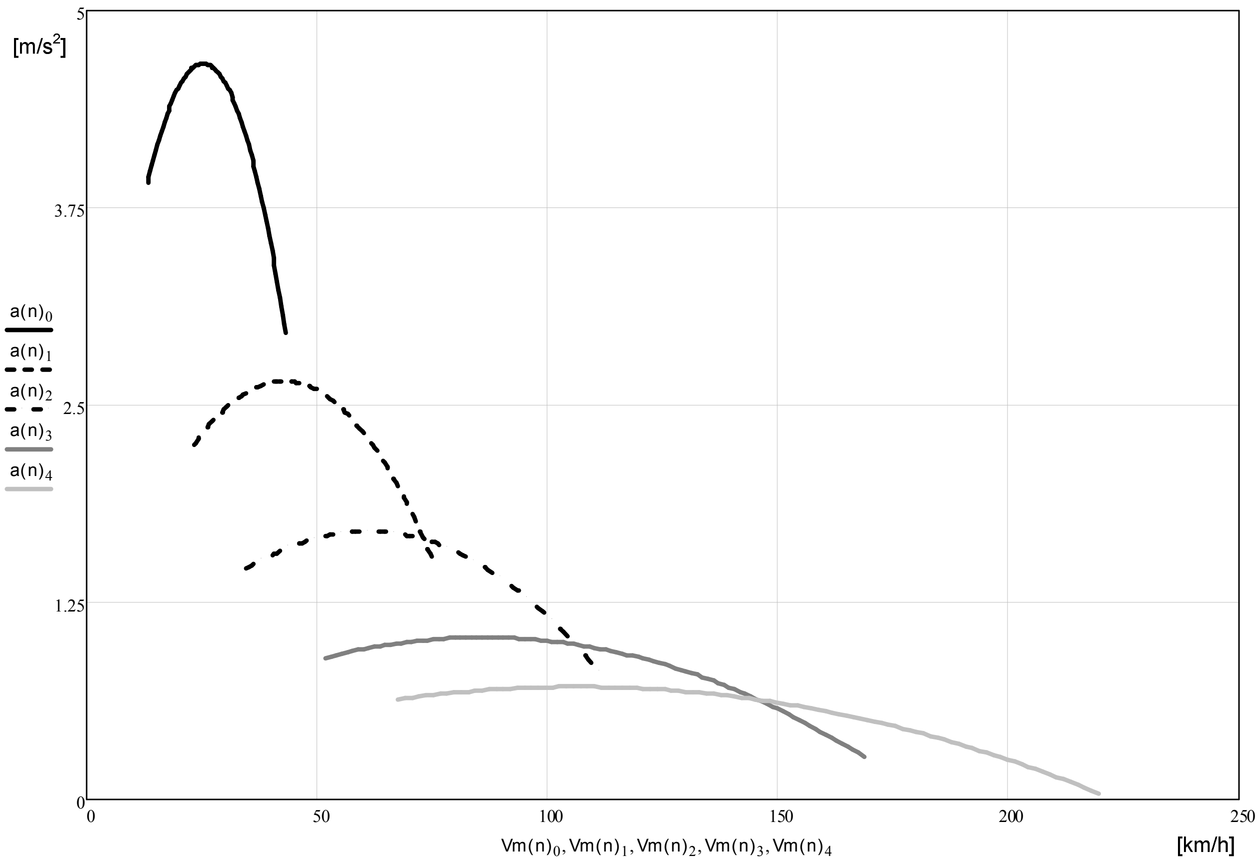

Fig. 2. The acceleration for the five gears.

The inertia and centrifugal forces. The next step in this study was to determine the inertia and centrifugal forces that act on the driver. Therefore it is considered a human model with its own mass of 80 [kg]. Because the influence of these external forces is more pronounced on the upper part of the body, in the driving position, the study is focused on the reactions of this upper body. When a person's upper body stands upright, the mass of the trunk, head and arms presses vertically on the lower lumbar spine with a force of approximately 55% of bodyweight, which in this case is 44 [kg] [1, 7].

To determine the inertia forces the following equation was used:

$$F_{acc}(n) = W_{ub} \cdot a(n). \quad (10)$$

Where:
- F_{acc} is inertia force;
- W_{ub} is the upper bodyweight.

As resulted in Fig. 1 and Fig. 2, it is also well-known that the vehicle's tangential forces at the wheel and acceleration have higher values in the first gear, and they decrease as the gear number and vehicle's speed increases. Thereby the inertia forces that act on the upper body have a range of high values at the vehicle start off, and they decrease as the speed gear number and vehicle's speed increases until the speed is constant. In Fig. 3 and 4 are represented the inertia force and the centrifugal force, that act on the upper body part of the human model while the vehicle is driven along a curvilinear trajectory starting with a radius of 1800 [m], 60 [m] radius in the middle, and exiting the curve with a radius of 1920 [m].

Because in the second part of this study it is used the AnyBody Modelling System software to simulate the three cases of driving, is important to mention that the simulation of each body movements is based on time steps [8]. Therefore the drive along the curvilinear trajectory is divided in 100 time steps.

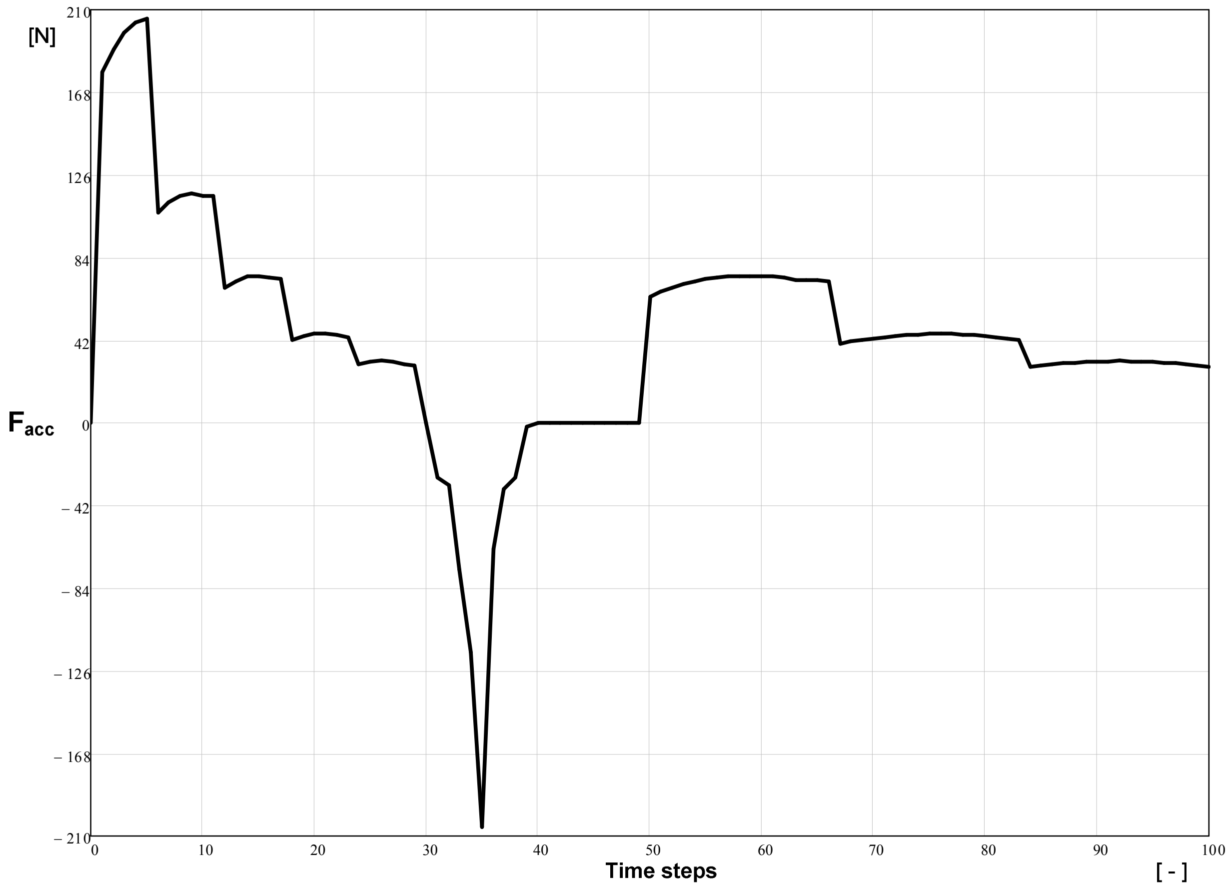

Fig. 3. The inertia force that act on the upper body part.

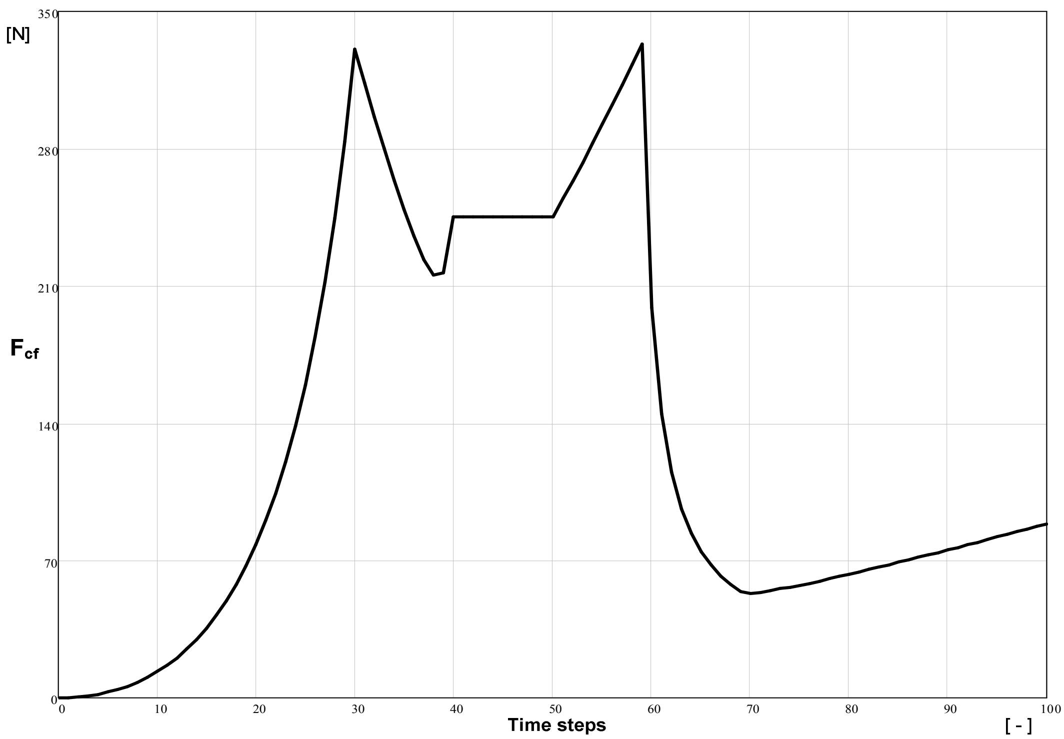

Fig. 4. The centrifugal force that act on the upper body part.

For the centrifugal forces, the following equation was used:

$$F_{cf}(n) = \frac{30 \cdot \left(\frac{V_m(n) \cdot 1000}{3600}\right)^2}{R_c(n)}. \tag{11}$$

Where R_c is the curvilinear trajectory's radius.

Simulation using AnyBody Modeling System software

The AnyBody Modelling System is a software system for simulating the mechanics of the live human body working in concert with its environment.

The body models are available in the standard demo package that can be used in conjunction with the AnyBody human body simulation software. Starting from a standing human model, using pre-defined muscles and bone attachments, and building the seated driving postures scenarios, have been developed.

For the seated position, the car seat was added virtually through a node that offers a stabile platform for the pelvis region. The angles for the legs were obtained from an ideal theoretical position for the purpose of minimizing their involvement in the general muscle activity of the body system.

All activities include certain tensions in the hands given by the steering wheel load. Because of this factor, the model has forces attached to the nodes belonging to each of the hands. This ensures that the data output is similar to that which would be obtained from a real life model and further adds to the accuracy of the model [8].

All movement patterns were carefully studied for muscle collision and kinematical correctitude; after all data was considered viable, the next phase of the study – using inverse dynamics, was conducted. The data was then extracted from the output of the program for the various muscle groups that were of interest (trunk muscles and abdominal muscle activity). The most relevant data was considered the trunk muscle fatigue. Muscle fatigue (Activity) is defined by the AnyBoby solver as muscle force divided by strength.

The simulation was made for three different cases each representing a car seat type and the way the human body is constrained to it.

The first case represents a standard car seat with the upper body of the human model poorly constrained to the backrest. On the upper body are acting the inertia force and the centrifugal force. Because the upper body it is poorly constrained to the backrest, results a movement on the resultant force direction, effort made to keep the balance in the car seat. The second case represents a car seat with lumbar support and the upper body constrained to the backrest. In this case the upper body moves only on the centrifugal force direction, with less effort made to keep the balance in the car seat. The third case represents a car seat with lateral trunk and lumbar supports. The upper body is constrained to the backrest and to the lateral trunk supports, and it is subjected to inertia and centrifugal forces. Because it is constrained on both force directions, results no movements and almost no effort made to maintain the balance in the car seat.

In Fig. 5 is represented the total muscle activity and in Fig. 6 the spine muscles activity, for each case of driving and car seat type. It is clearly reviled that in the first case that the energy consumption has higher values and that in the third case the effort made to keep the balance in the car seat is minimal.

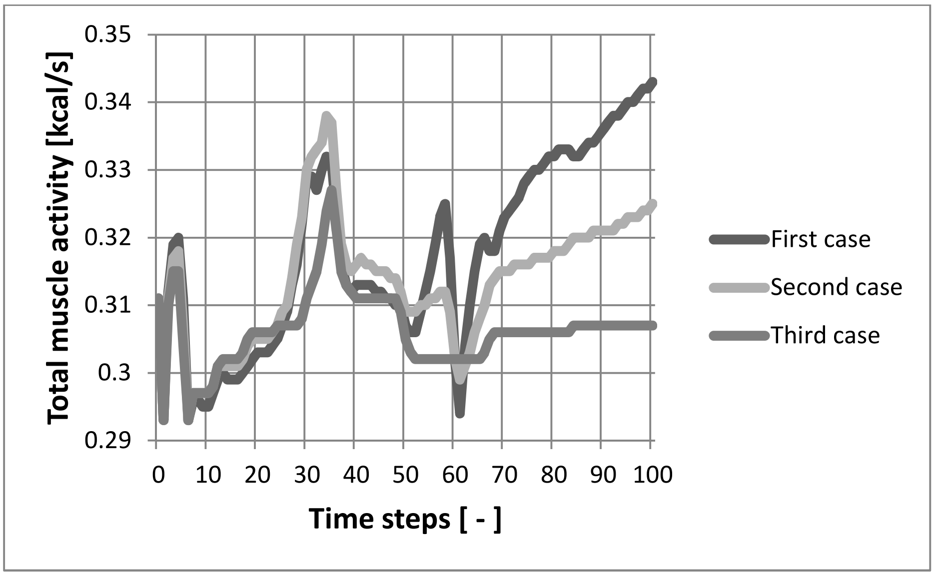

Fig. 5. The total muscle activity for each case.

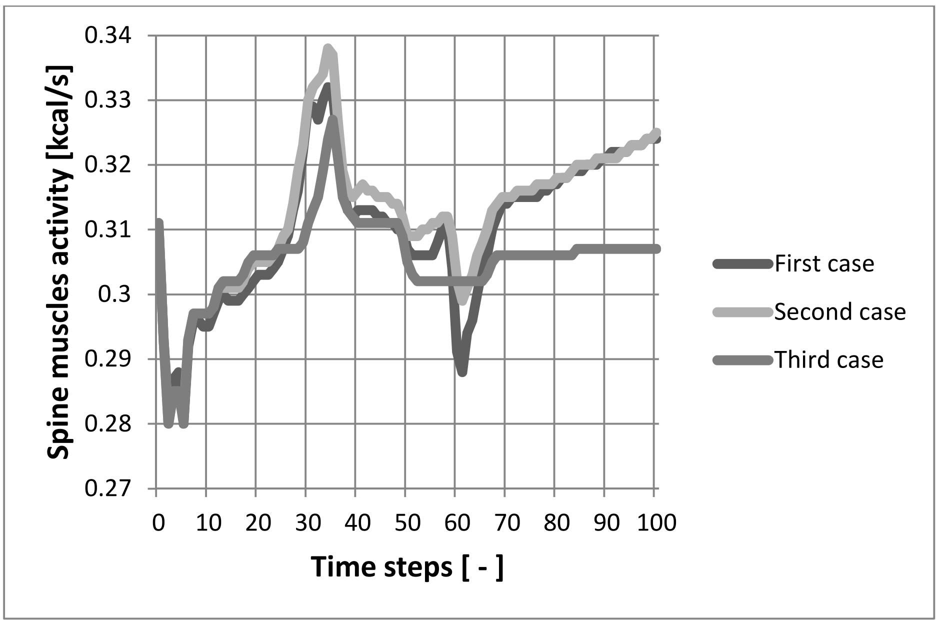

Fig. 6. The spine muscles activity for each case.

Conclusions

Back pain is one particularly crucial problem that is in a driver's best interest to avoid. A good driving position and correct posture is vital for the efficient practice driving and to avoid chronic back pain.

After a careful examination of the data and statistical analysis, a clear distinction between the energy consumption for the three driving postures became apparent. According to the results the ergonomically optimal driving posture is the 3^{th} case representing a car seat with lateral trunk and lumbar supports.

These results are highlighting the importance of the car seat designed with trunk lateral and lumbar support that has to be comfortable; it should fit to lumbar curvature, and contact should be maintained with it while driving.

Another aspect of the study is the possibility of pointing out the individual muscle strain for the various trunk muscles. This sort of data obtained from driving posture simulations, is very useful in ergonomic design of the car seats, and also in improving the prevention of the musculoskeletal disorders by using ergonomics.

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