Are Students' Conceptions about Automobile Braking Distances Correct?

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INTRODUCTION

Our motivation for the work part of which we present in this contribution have been facts some of which we will now give. In the evening's News one can often encounter a piece of news describing a car accident involving young people who overestimated their abilities or the capabilities of their motor vehicle. In many cases these accidents end tragically and we are only informed that the driver hasn't adjusted his/her drive to the nature and the state of the road.

It was not so long ago (January 2012) when the finalist of the first serie of the Slovak Superstar driving BMW perished. His car in the course of overtaking a van and getting into its driving lane skidded, went off the road and at a speed of 140 km/h (as the witnesses claim) crashed on a tree. Due to this crash the vehicle snapped off into three pieces and the body of one of the two victims who were instantly dead was catapulted several tenths of meters from the vehicle.

According to the Federal Statistical Office of Germany in 2011 died as a consequence of car accidents 522 young people aged between 18 and 24 years. Young people usually drive older vehicles that are not equipped with modern safety systems. It often happens that they go off the road due to the loss of control of the vehicle. We just note that among the 18 to 24 years old German drivers there are two

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times more of those who don't fasten their seatbelts than among the rest of the drivers.

The facts such as those just stated led us to the start of an investigation of the conceptions and the knowledge of young people who possess a driver's licence about some aspects of the road traffic, particularly about the braking characteristics of motor vehicles. Are the young people sufficiently prepared concerning this area? Do they know what should be the speed of the car they are driving if it should be stopped at a sufficient distance from an obstruction and if they don't, what may be the possible ways to rectify this lack of knowledge? The present paper deals exactly with the answers to these questions.

1 TESTING OF THE STUDENTS' CONCEPTIONS

For the purposes of our investigation we tested the conceptions about the car braking distances of the first year students at the University of Žilina. The task imposed on the students was the following [1]: *Find the braking distances of the automobile Škoda Octavia 1.6 LX that begins to brake when moving at speeds 20, 40, 60, 80 a 100 km/h along an asphalt road. The car is driving on summer tires and the driver is braking by totally flooring the brake pedal.* (The roadway surface was a little wet after a small rain. Since the vehicle doesn't have the system ABS, the measured braking distance corresponds to braking in slide.) The testing of the students was performed two times – before and after watching a video that contained recordings of braking starting at above mentioned initial speeds. We call this a pre-test and a post-test, respectively. The students also had to answer the questions whether they drove a car and whether they already had been involved in a car accident with the following result: 77% of the students drive a car and 22% have been already directly involved in a car accident.

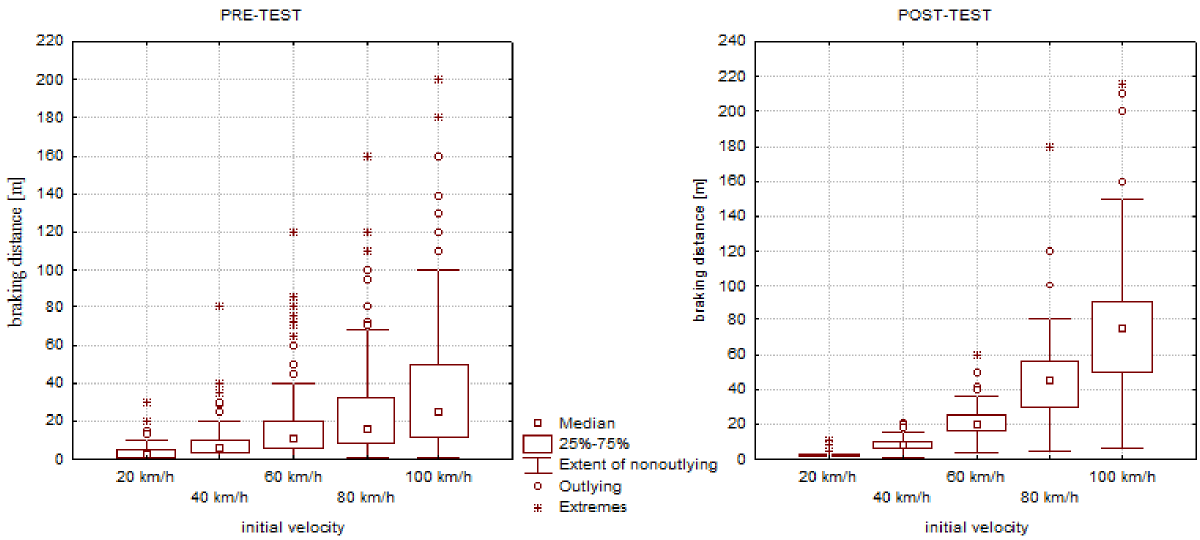

Fig.1. Box graphs of the initial and final estimates of the car braking distances, *i.e.* the estimates made before and after watching a video, for Škoda Octavia 1.6 LX.

The pre-test and the post-test were performed on a sample of 325 students. As it is obvious, from each student we collected ten answers – five initial braking distances estimates for each of the above given initial speeds and five final braking distances estimates for each of these initial speeds. In this way we obtained ten files of 325 values each – five files in case of the pre-test and five files in case of the post-test. These data are depicted by means of box graphs in Fig. 1. Here the median was calculated as the mean value of the obtained braking distances that were arranged in a nondescending progression and the extreme values, *i.e.* the values loaded with a nonrandom error, were identified using the Grubbs's test of extreme values. If among a student's answers such an extreme braking distance value was found at least once, the data corresponding to his/her answers were excluded from all five (pre-test or post-test) of our data files. This resulted in (five) sample files of 311 values each in case of the pre-test and (five) sample files of 316 values each in case of the post-test. These sample files were then subjected to further statistical processing that is described in the next section.

2 STATISTICAL ANALYSIS OF THE RESULTS

If there is a difference between the students' car braking distances estimates and the true values of these quantities, then our aim is using the collected data to find out whether this difference is caused only by a *random error*, in which case the students' conceptions about the car braking distances are correct, or also by a *systematic error*, *i.e.* these conceptions are incorrect. To fulfill this task we used our sample data files to perform the Student's t-test (in the following text just "t-test", look *e.g.* at references [2]). This test is used when one wants to determine the population mean of some quantity in case we have data only from a sample or several samples selected out of the whole population that are much smaller than this population. Thus these data form sample data files of much shorter length than would be the length of a file corresponding to the whole population. Obviously we have only one sample data file representing the whole population for a particular initial speed and before or after watching the video.

However, the t-test can be applied only in case when one can reasonably expect the population distribution of the investigated quantity to be normal (in the following text we will just use the phrase "the population is normal") [3] or when the sample files are large, *i.e.* the number of data in a sample file is $n \geq 30$. Then the distribution of the means of the sample files around the true value of the investigated quantity is also normal and that is what one needs to be able to use the t-test. In our case we "measure" many times the same quantity – the car braking distance at some initial speed either before or after watching the video. Thus it is reasonable to assume that our population (*e.g.* all university students in Slovakia) is normal, *i.e.* our measurement is subject to a random error. When our population isn't normal but our sample files contain data loaded with a random error and are large (which is true in our case), one can use the central limit theorem and the law of large numbers to justify the application of the t-test to these data. But our data can be also loaded with a systematic error, which would manifest itself by a shift of the whole bell shaped Gauss distribution in case our population is normal or of the distribution for the case when our population isn't normal but our sample is large. This would mean that the true value of the population distribution of the student's car braking distances estimates is not equal to the expected value of this quantity.

Armed with the above stated ideas we can now describe the procedure of applying the t-test to our data. We test the null hypothesis H_0 against the two-sided alternative hypothesis H_1 at the significance level $\alpha = 5\%$ for each of our ten files of the braking distances values:

H_0: $\mu = d_y$: The true value of the distribution of the car braking distances estimates for the whole population is equal to the expected braking distance.

H_1: $\mu \neq d_y$: The true value of the distribution of the car braking distances estimates for the whole population is not equal to the expected braking distance.

As it is obvious from Tab. 1, the quantity d_y which was obtained by means of the videoanalysis using the program Tracker [4] represents the theoretical (expected) value of the car braking distance. By means of the one-sample t-test we wanted to find out whether this theoretical value is consistent with the students' observations. To this end we calculated for each of our ten sample data files a 95% two-tailed confidence interval for the true value μ if the parameter σ^2, *i.e.* the square of the standard deviation of the distribution of the car braking distances estimates for the whole population, is unknown according to the prescription [5]

$$\langle \overline{X}_n - t_{\alpha,n-1} . \frac{S_n}{\sqrt{n}}, \overline{X}_n + t_{\alpha,n-1} . \frac{S_n}{\sqrt{n}} \rangle \quad (1)$$

where $t_{\alpha,n-1}$ is the critical value of the Student's t-distribution with $n - 1$ degrees of freedom and the same true value μ as it has the distribution of the car braking distances for the whole population. These critical values for the significance level $\alpha = 5\%$ we evaluated in Excel. They can also be found on the World Wide Web, *e.g.* at links found in [2].

Obviously in the above formulas $n = 311$ in case of an initial estimates sample file and $n = 316$ in case of a final estimates sample file. The quantity

$$\overline{X}_n = \frac{1}{n} \sum_{i=1}^{n} X_i \quad (2)$$

is the sample mean and the quantity

$$S_n^2 = \frac{1}{n-1} \sum_{i=1}^{n} (X_i - \overline{X}_n) \quad (3)$$

is the square of the sample standard deviation. We note that this formula represents the most commonly used estimator of σ^2 and at the same time it is the unbiased estimator of the variance of the normal distribution.

Both upper and lower limits of the confidence intervals (1) for each of our ten sample data files in case of $\alpha = 5\%$, *i.e.* in case we have 95% confidence intervals, are given in Tab. 1. The statement "95% confidence interval" means that if we calculated many such confidence intervals using many sample files that would represent the measurement of the same quantity, 95% of these intervals would contain the true value μ of the distribution of this quantity. We stress that our ten sample data files each represent measurement of the same but different quantity. Thus our population for each of the ten cases is represented only by one sample file.

Subjecting our data to the t-test means the following: In case that d_y falls within the limits of our 95% confidence interval, the hypothesis H_0 is confirmed, *i.e.* at the 5% significance level the difference between the true value of the braking distance and the braking distance found from the students' estimates is due to only a random error and thus the students' conceptions about this quantity are correct. In the opposite case, *i.e.* when d_y doesn't assume a value from our 95% confidence interval, the hypothesis H_0 is rejected at the significance level of 5% and the hypothesis H_1 is accepted. This means that the difference between the true value of the car braking distance and the braking distance found as the mean of the students' estimates is caused by a systematic error since the whole interval (1) is shifted with respect to the theoretical value of the car braking distance d_y. Thus in this case the students' conceptions about the car braking distances are incorrect.

Table 1. Sample mean values, squares of sample standard deviations, lower and upper bounds of the confidence intervals (1) for *α = 5%*, initial speeds and braking distances obtained by means of Tracker for automobile Škoda Octavia 1.6 LX.

initial speed (tachometer)	20 km/h	40 km/h	60 km/h	80 km/h	100 km/h
$\overline{X}_n$ [m] (pre-test)	3.13	7.14	13.78	21.57	32.57
S_n^2 [m]	3.16	6.62	11.60	17.89	27.07
lower bound of the confidence intervals (1) for *α = 5%* [m]	2.78	6.40	12.49	19.58	29.55
upper bound of the confidence intervals (1) for *α = 5%* [m]	3.48	7.88	15.08	23.57	35.59
braking distances d_y found using videoanalysis [m]	2.39	7.37	21.67	43.62	73.67
$\overline{X}_n$ [m] (post-test)	2.22	7.61	21.91	43.59	72.73
S_n^2 [m]	0.82	2.64	8.96	18.40	33.17
lower bound of the confidence intervals (1) for *α = 5%* [m]	2.13	7.32	20.92	41.56	70.03
upper bound of the confidence intervals (1) for *α = 5%* [m]	2.31	7.90	22.90	45.63	77.37
initial speeds found using videoanalysis [km/h]	19.89	36.28	57. 43	76.51	95.01

Applying the above ideas to our concrete data we see looking at Tab. 1 that in case of the initial estimates $\overline{X}_n$ of the car braking distances the expected value d_y (turquoise) in 4 cases out of 5 doesn't fall into the 95% confidence interval for the true value μ (red). Hence we reject the hypothesis H_0 and accept the hypothesis H_1 meaning that the students' estimates of the car braking distances are loaded with a systematic error, *i.e.* their conceptions about these quantities are incorrect. On the other hand we can see in Tab. 1 that in case of the car braking distances estimates $\overline{X}_n$ made by the students after watching the video the theoretical value d_y in 4 out of 5 cases falls within the limits of the 95% confidence intervals for the true value μ (yellow). Hence we accept the hypothesis H_0, *i.e.* we can state that in this case our data are loaded only with a random error, which means that the conceptions of the students about the car braking distances are correct after watching the video.

3 VIDEOANALYSIS OF THE BRAKING DISTANCES OF MORE AUTOMOBILES

As it follows from the above results, the analysis and the videoanalysis of the car braking distances form and in a positive manner affect the students' imagination. Thus by means of innovative methods it is possible to improve the level of the students' knowledge [6, 7]. Therefore, in collaboration with the students and the faculties of the University of Žilina we prepared more videos on which the videoanalysis could be performed. Using these videos we could compare the car braking distances for cases when the car is driving on summer or winter tires and when it is braking on a wet or a dry road. For these purposes we used videorecords of braking of the automobiles Škoda Felicia 1.3 LX and Fabia Monte Carlo 1.2 TSI, Volkswagen Polo, Citroën C6 3,0i V6, Renault Thalia and Mazda 3 at the airport with asphalt surface that is located in the township Rosina near the town Žilina. The results of these analyses are illustrated in Fig. 3, 4a.

When performing the analysis of braking of these automobiles on a both dry and wet road we found that the braking distances, initial speeds and decelerations obtained by means of the videoanalysis using Tracker were in a good agreement with those obtained using commercial methods [8]. The videoproblem relating to this analysis that is posted on the WWW (http://hockicko.uniza.sk/Priklady/videopriklady.htm) is given in Fig. 2. Using these videos we could demonstrate to the students that the braking distance dramatically increases with speed [9].

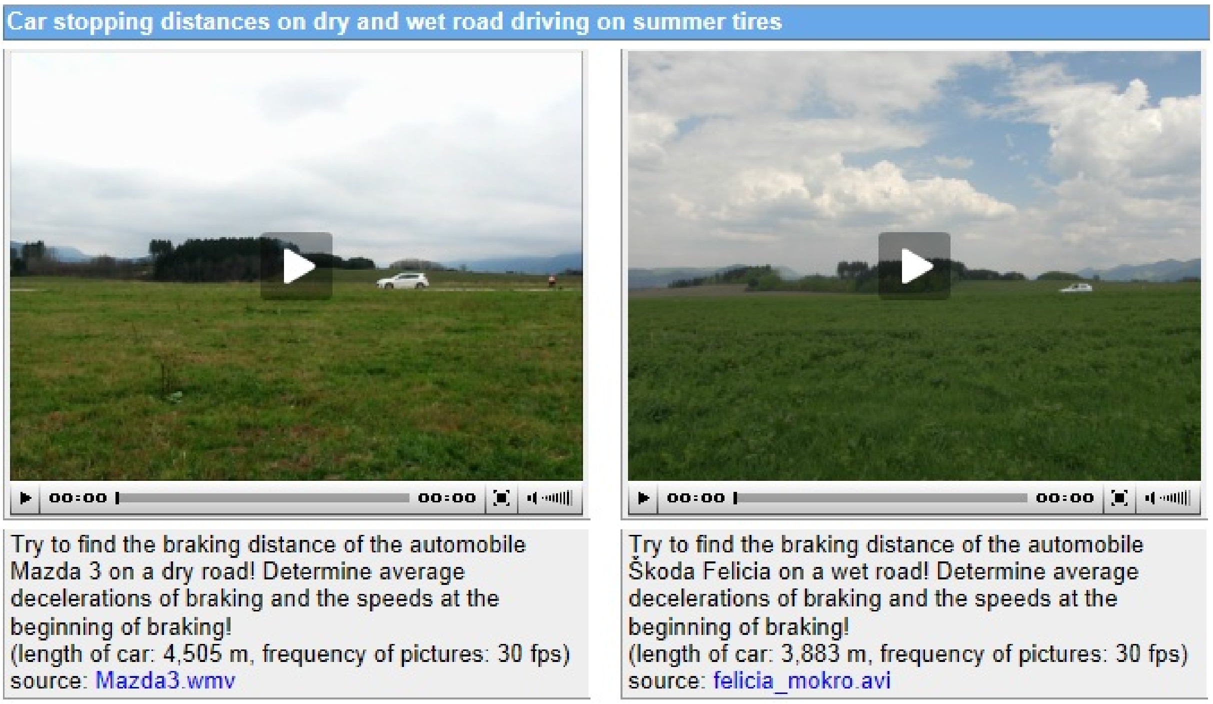

Fig. 2. The videoproblems posted on the World Wide Web designed for the purpose of the analysis of the car braking distances on both a dry and a wet road.

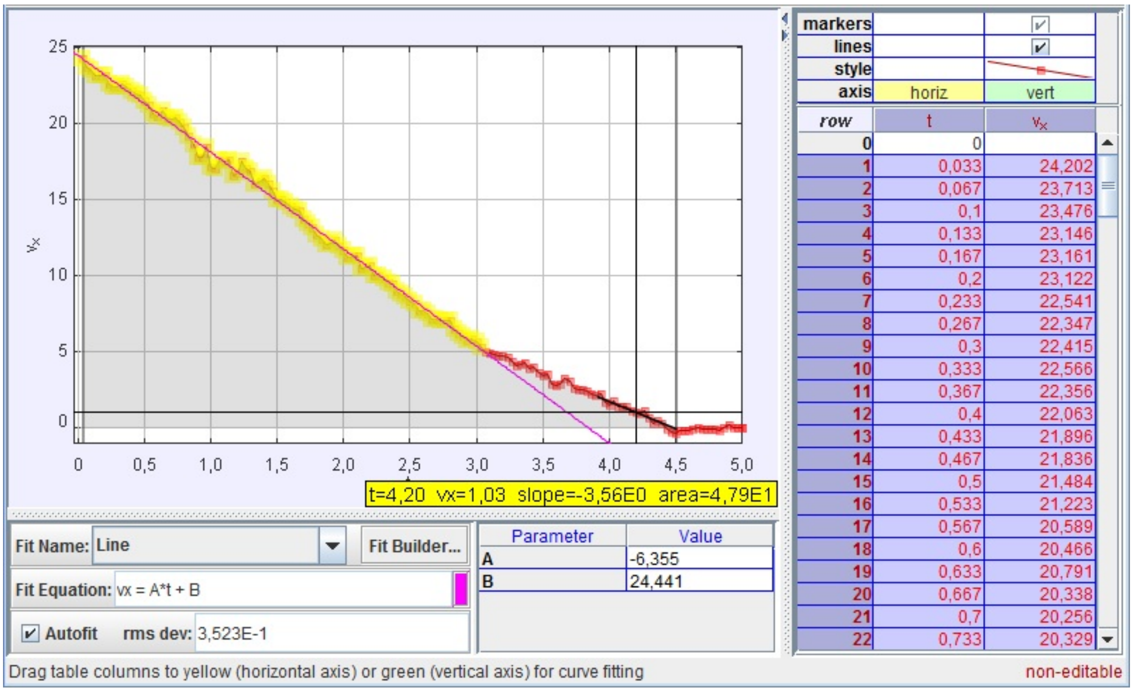

Fig. 3. Analysis of braking of the car Škoda Felicia 1.3 LX by means of the program Tracker (Data Tool) ([v_x] = m/s, [t] = s, a = -6.36 m/s^2, from t = 3s a = -3.56 m/s^2).

Fig. 3 depicts the dependence of the speed of the car Škoda Felicia 1.3 LX on time in the course of braking obtained by means of Tracker. At the time of approximately 3.0

seconds one of the wheels was blocked resulting into subsequent skidding. The figure clearly demonstrates how the time of braking and thus the braking distance are affected by braking in the course of skidding (deceleration decreased). From the parameters of this motion obtained by fitting it was possible to determine the speed at the start of braking (v = 87.99 km/h (24.44 m/s)), the time of braking (t = 4.5 s), the deceleration of the motion (a = -6.36 m/s^2, from t = 3 s a = -3.56 m/s^2) and the braking distance (d = 47.9 m).

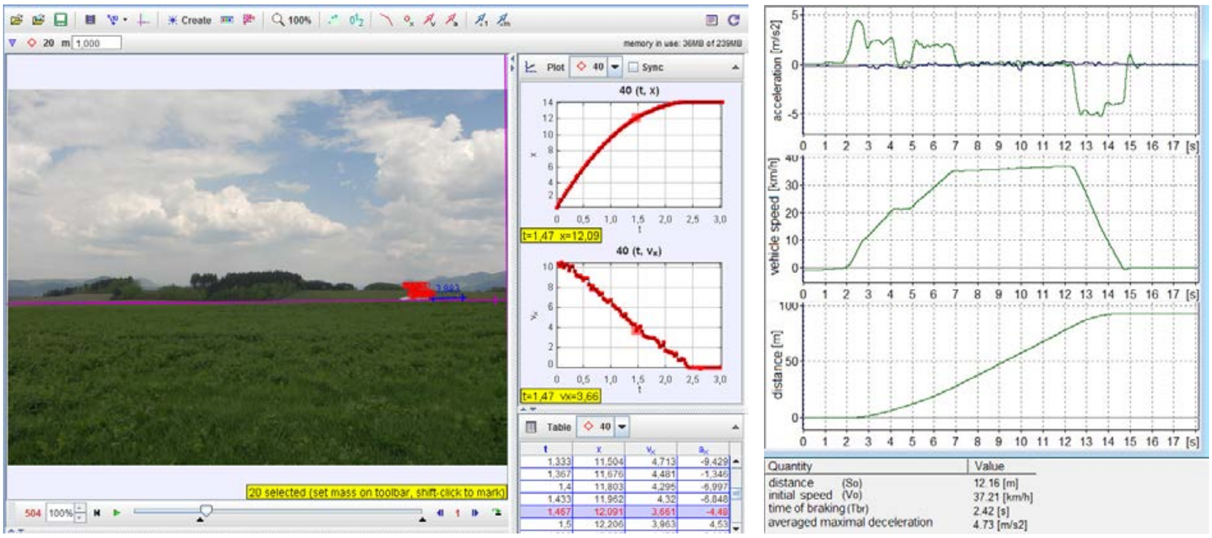

Fig. 4. a) Video analysis of braking of the car Škoda Felicia obtained by Tracker (wet road). b) Analysis of the whole process, accelerating and braking using XL MeterTM.

There exist several commercial devices that are able to accurately and instantaneously determine the braking distances, the initial speeds, the time of braking and the average deceleration during braking [10]. Fig. 4a shows the recording of the process of braking of the automobile Škoda Felicia and the time dependencies of the distance and the speed in the course of braking obtained using Tracker. Fig. 4b demonstrates an output from the device called the XL meter that presents recordings of the time dependencies of the instantaneous acceleration, the instantaneous speed and the distance gone by the car Škoda Felicia on a wet road. As it can be seen, from these recordings it is possible to determine times at which the driver changed gears, the magnitude of the average acceleration at a certain gear, the way the acceleration was changing and the way the automobile was braking.

4 SUMMARY

As stated in the above text, about 77% of students drive a car and about **22%** of them were already involved in a car accident. One of the possible causes of the numerous car accidents may be incorrect students' conceptions about the car braking distances. In this contribution we have shown by means of statistical methods that the deviation of the students' braking distance estimates from the real values of this quantity is not caused by a random but by a systematic error. As we have seen, however, after watching the car braking video recordings the students' car braking distances estimates were corrected meaning that the deviations of these estimates from the real values were caused only by a random error.

To conclude the present paper has demonstrated that the videoanalysis in an appropriate way forms the correct students' conceptions about the car braking distances under various conditions. Using videos and other multimedial aids affects in a positive manner the level of the students' knowledge, understanding, retention, specific transfer and active learning. These findings may in the future help decrease the car accident rate on the roads and increase the responsibility of mainly young drivers who are often involved in serious car accidents.

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