Analysis of Braking Response Time for Driving Take Based on Tri-axial Accelerometer

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Purpose: Driving a car is an essential component of daily life. For safe driving, each driver must perceive sensory information and respond rapidly and accurately. Brake response time (BRT) is a particularly important factor in the total stopping distance of a vehicle, and therefore is an important factor in traffic accident prevention research. The purpose of the current study was (1) to compare accelerometer-BRTs analyzed by three different methods and (2) to investigate possible correlations between accelerometer-BRTs and foot switch-BRTs, which are measured method using a foot switch.

Methods: Eighteen healthy subjects participated in this study. BRT was measured with either a tri-axial accelerometer or a footswitch. BRT with a tri-axial accelerometer was analyzed using three methods: maximum acceleration time, geometrical center, and center of maximum and minimum acceleration values.

Results: Both foot switch-BRTs and accelerometer-BRTs were delayed. ANOVA for accelerometer BRTs yielded significant main effects for axis and analysis, while the interaction effect between axis and analysis was not significant. Calculating the Pearson correlation between accelerometer-BRT and foot switch-BRT, we found that maximum acceleration time and center of maximum and minimum acceleration values were significantly correlated with foot switch-BRT ($p<0.05$). The X axis of the geometrical center was significantly correlated with foot switch-BRTs ($p<0.05$), but Y and Z axes were not ($p>0.05$).

Conclusion: These findings suggest that the maximum acceleration time and the center of maximum and minimum acceleration value are significantly correlated with foot switch-BRTs.

Keywords: Brake response time, Foot-switch, Tri-axial accelerometer

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I. Introduction

Driving a car is an essential component of daily life. For safe driving, a driver must perceive sensory information and respond rapidly and accurately.[1] Healthcare professionals should be concerned with monitoring individuals with driving disabilities, both for their safety and for the safety of others. Many physicians make recommendations for resumption of driving by individuals.[2-4] But, these recommendations, to date, have been made empirically without scientific data.

Brake response time (BRT) is an important in driving. It requires visuo-motor coordination to cope with unexpected conditions or traffic lights, and BRT may an objective measure of driving capability.[5] For common clinical assessment, BRT has usually been measured using a foot switch with a built-in force sensitive resistor, which has usually been used to determine the time at which the plantar surface contacts the brake pedal. [6,7] But in this method it is difficult (i) to precisely determine the contact point if the foot has structural and pathological problems, and (ii) to find the direction and magnitude of movement.[8] On the other hand, a tri-axial accelerometer is less influenced by those problems and can assess characteristics of movement regarding timing, speed, frequency, and distance on 3 axes (X, Y, and Z axes). Also this method is a low-cost one, is easy to carry out, and is convenient.

There are many methods for defining the time when the braking or acceleration motions occur.[9,10] We selected three of them and the motion signals are processed with them. The three are: maximum acceleration time, geometrical center and center of maximum and minimum acceleration values.

The purpose of the current study was to compare accelerometer-BRTs which are analyzed by three different methods and to quantify correlations between accelerometer-BRTs and foot switch-BRTs that are measured using a foot switch.

II. Methods

1. Subjects

A total of 18 healthy subjects (9 females, 9 males) participated in our study. Eligibility criteria for inclusion of elderly in the study included: intact visual perception and cognition, no musculoskeletal disease, normal sitting balance. Before the experiment, its purpose and methods were fully explained to subjects to help their understanding of the study. Mean age was 22.3±2.1 years; mean height was 168.2 cm; mean weight was 64.4 kg. Informed consent was obtained from each subject.

2. Materials and procedures

A TUCSON (HYUNDAI Inc, Korea) was modified for study in a car laboratory. A foot switch was attached to the middle surface of the accelerometer and the brake pedal. A foot switch with a built-in force sensitive resistor (TSD111A, Biopac ins, USA) was used to determine the time delayed for contacting the brake pedal with the right foot. Also, a tri-axial accelerometer was attached at the lateral malleolus of the right foot. Acceleration signals were measured on a triple axis: the X-axis represented acceleration in the medio-lateral direction; the Y-axis represented the up and down direction; the Z-axis represented the antero-posterior direction.

Subjects sat in the driver's seat and then adjusted the height and inclination of the car seat to maintain a comfortable posture. The height of the heel was [limited below 5 cm]. All subjects were given the same instruction regarding the driving reaction time measurement. The subjects were instructed that as soon as a red right appeared on the monitor they were to place their right foot on the brake pedal as quickly as possible. To prevent stimulus onset anticipation, variable interstimulus periods were randomly presented. The subjects were given three practice trials and then 5 trial runs. The highest and lowest reaction times were eliminated and the remaining three trials were averaged. Acceleration signals were sent to an MP150 A/D converter, and then to "Acknowledge" software (Biofac System Inc, USA) for PC processing.

3. Data analysis

1) Maximum acceleration time

The maximum acceleration time (T_{max}) was the most basic criterion among all the methods presented. The concept of maximum acceleration time is graphically described in Figure 1 for a representative acceleration signal. As shown in the figure, the time until motion occurrence was defined as the time span between the reference time and the point of occurrence of the absolute maximum value. In other words, we measured when the greatest acceleration occurred (Figure 1).

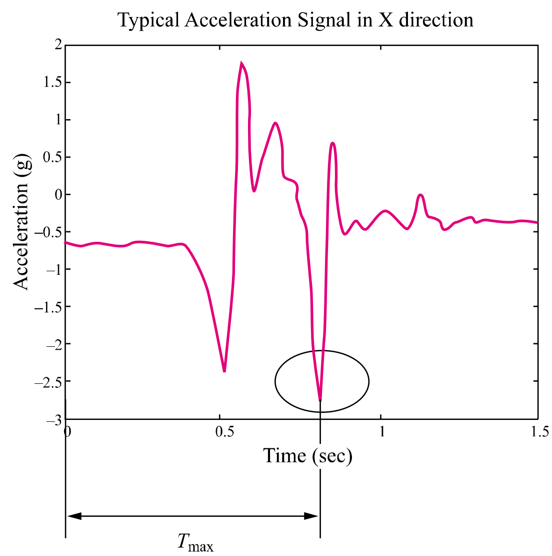

Figure 1. Criteria 1: absolute maximum peak occurrence time.

2) Geometrical center (T_{geo})

To estimate the whole motion, the absolute version of the original signal (shown in panel (b) of Figure 2 was calculated. If this process is omitted, the positive and negative values of acceleration will sum to almost zero. Then the mass center of the absolute value signal is calculated using the following well-known equation and this was the second measure of motion occurrence[11] (Figure 2).

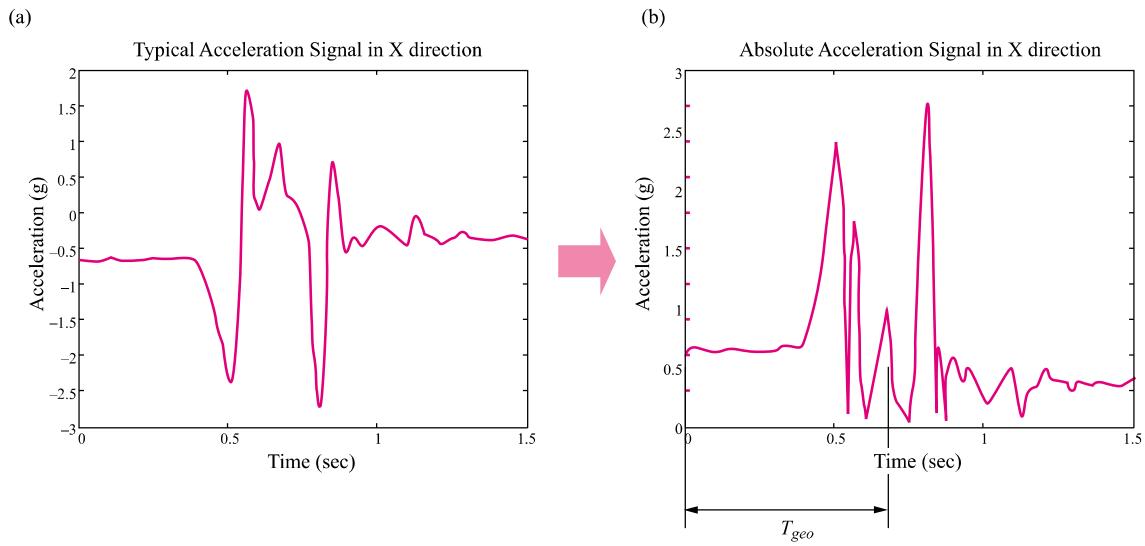

Figure 2. Criteria 2: geometrical center of whole motion signal.

$$T_{geo} = \frac{\sum_i |y_i| t_i}{\sum_i t_i}$$

where y_i is the sampled acceleration signal and t_i the sampling time.

3) Center of maximum and minimum acceleration

All motions included the positive maximum and the negative minimum pair, which are shown in Figure 3. Moreover, this peak pair of maximum and minimum appears twice during each motion. The features reflect the start of acceleration of motion and the final deceleration of motion. This final criterion was obtained by calculating the center between the preceding

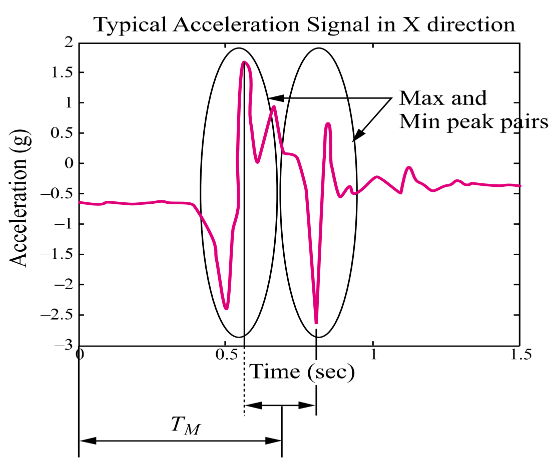

Figure 3. Criteria 3: Arithmetic average value between maximum and minimum peaks.

maximum peak and the accompanying minimum peak peak[12] (Figure 3).

4. Statistical analysis

The mean of the five trials was used as the summary measure. Two-way ANOVA was used to compare the different methods of analysis and the 3 axes. The Pearson correlation was used to find the correlation between the accelerometer-BRT and the foot switch BRT. An alpha level of <0.05 was used as the level of significance. All statistical analysis was performed using SPSS 12.0 for Windows (SPSS Inc, Illinois).

III. Results

The data for our 12 subjects was pooled for analysis. The mean and standard deviation of the accelerometer-BRTs are shown in Table 1. ANOVA yielded significant main effects for axis ($F=3.17$, $p=0.05$) and analysis ($F=55.07$, $p=0.00$). The interaction effects between axis and analysis were not significant ($F=1.42$, $p=0.23$).

The mean value for foot switch-BRTs was 0.96±0.26. Pearson correlations were calculated between the three types of accelerometer-BRTs and foot switch-BRTs, maximum acceleration time and center of maximum and minimum acceleration values. Accelerometer-BRTs were significantly correlated with foot switch-BRTs ($p<0.05$)(Table 2). But, the geometrical center was not significantly correlated with foot switch-BRTs ($p>0.05$).

Table 1. Accelerometer-BRT by 3 types of analyzing methods

Analyzing methods	Axis	Accelerometer-BRT
T_{max}	x	0.64±0.14
	y	0.65±0.15
	z	0.65±0.13
T_{geo}	x	0.82±0.12
	y	0.95±0.04
	z	0.97±0.06
Center of T_{max} and T_{min}	x	0.64±0.12
	y	0.66±0.11
	z	0.68±0.13

T_{max}: maximum acceleration time
T_{geo}: geometrical center
center of T_{max} and T_{min}: center of maximum and minimum acceleration time

Table 2. The correlation between accelerometer-BRT and foot switch-BRT

Analyzing methods	Axis	Accelerometer-BRT
T_{max}	x	0.74*
	y	0.83*
	z	0.91*
T_{geo}	x	0.83*
	y	0.30
	z	0.35
Center of T_{max} and T_{min}	x	0.84*
	y	0.93*
	z	0.93*

T_{max}: maximum acceleration time
T_{geo}: geometrical center
center of T_{max} and T_{min}: center of maximum and minimum acceleration time
*$p<0.05$

IV. Discussion

BRT is an important factor in the total stopping distance of a vehicle and is therefore an important factor in traffic accident prevention research.[3,13] In a study by Spalding and colleagues, the BRT was defined as the time interval between signal initiation and achieving a pressure of 100 N on the brake pedal. For technical reasons, we defined the brake response time as the time interval between the lighting up of the LED and the first contact with the brake pedal.[3]

Accurate measurement of physical activity is a prerequisite to monitor population health and design effective interventions. Accelerometers are one of the most commonly used methods for objectively measuring physical activity under field conditions. They are small, noninvasive devices that measure the rate of acceleration (i.e. intensity) produced by body movement in one (vertical; uniaxial) or three planes (anterior-posterior, lateral, and vertical; triaxial).

It is difficult for older people or disabled people to properly judge traffic environments and to stop initiated movements [on the way?].[5] Therefore, for safe driving, drivers must perceive and respond to sensory information as as fast and as accurately as possible. This is one of the fields that has been studied in traffic accident prevention because delayed brake response time following an unexpected external stimulus is a leading cause of traffic accidents. Healthcare professionals should be concerned with monitoring an individual's ability to drive, and make recommendations for resumption of driving for disabled individuals, both for their safety and for the safety of others.

It is important to specify the time when braking or acceleration motions occur and there are many methods for defining it. Among them, three methods were deliberately selected and the motion signals of our subjects were analyzed using them. The three methods were: maximum acceleration time, geometrical center and center of maximum and minimum acceleration values.

First, the maximum acceleration time (T_{max}) is the most basic criterion among all the presented methods. Maximum acceleration time is also very simple and intuitive, but this method can be very inconsistent. For example, there is another peak value at t=0.5 second in the signal presented in Figure 1. This peak is comparable to a maximum in magnitude but not maximum. The difference in magnitude between these two peaks was not so big that they were liable to influence each other. In addition, this method cannot give us any information about the overall motion. It only specifies the maximum acceleration point. The second method, the so called 'geometrical center (T_{geo})', was devised to estimate overall motion. The last method is called 'center of maximum and minimum acceleration'. Although the second criterion was devised to take overall motion into account, the characteristic features of the acceleration and braking motions are not considered. One of these features is that all the motions include the positive maximum and the negative minimum pair which are shown in the Figure 3. Moreover, this peak pair of maximum and minimum values appears twice for each motion. These features reflect the starting acceleration and final deceleration of motion. The final criterion is obtained by calculating the center between the preceding maximum peak and the accompanying minimum peak. With this criterion, it is possible to take both the dominant motion and the whole motion span into account simultaneously.

In the present study, we compared the three methods to analyze BRT using the tri-axial accelerometer, and intended to find correlation between three types of accelerometer-BRT and foot switch-BRT. ANOVA model on accelerometer-BRT yielded significant main effects for axis and analysis. In Correlation between accelerometer variables and foot switch variable, $T_{\max}$ and Center of $T_{\max} - T_{\min}$ were significantly correlated with foot switch-BRT. Center of $T_{\max} - T_{\min}$ correlated more highly with foot switch-BRT than $T_{\max}$.

Therefore, we suggests that accelerometer-BRT shouldbe interpreted differently as the analyzing method changes and may be novel and user-friendly methodology that allows for the assessment of timing variability in BRT in driving capabilities.

V. Conclusion

We suggest that accelerometer-BRT should be interpreted differently as the analyzing method changes and Center of $T_{\max} - T_{\min}$ were more significantly correlated with foot switch-BRT, comparing $T_{\max}$ Accelerometer-BRT may be novel and user-friendly methodology that allows for the assessment of timing variability of BRT in driving capabilities.

Author Contributions

Research design: Shin HK
Acquisition of data: Shin HK
Analysis and interpretation of data: Lee HC
Drafting of the manuscript: Shin HK, Lee HC
Research supervision: Shin HK

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