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Difference between car-to-cyclist crash and near crash in a perpendicular crash configuration based on driving recorder analysis

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ABSTRACT

Analyzing a crash using driving recorder data makes it possible to objectively examine factors contributing to the occurrence of the crash. In this study, car-to-cyclist crashes and near crashes recorded on cars equipped with advanced driving recorders were compared with each other in order to examine the factors that differentiate near crashes from crashes, as well as identify the causes of the crashes. Focusing on cases where the car and cyclist approached each other perpendicularly, the differences in the car's and cyclist's parameters such as velocity, distance and avoidance behavior were analyzed. The results show that car-to-cyclist crashes would not be avoidable when the car approaching the cyclist enters an area where the average deceleration required to stop the car is more than 0.45 G (4.4 m/s^2). In order for this situation to occur, there are two types of cyclist crash scenarios. In the first scenario, the delay in the drivers' reaction in activating the brakes is the main factor responsible for the crash. In this scenario, time-to-collision when the cyclist first appears in the video is more than 2.0 s. In the second scenario, the sudden appearance of a cyclist from behind an obstacle on the street is the factor responsible for the crash. In this case, the time-to-collision is less than 1.2 s, and the crash cannot be avoided even if the driver exhibited avoidance maneuvers.

1. Introduction

In recent years, many studies have investigated vehicle crashes by making use of driving recorders (Kamata et al., 2006; Shino et al., 2008, 2010). One of the benefits of analyzing a crash using driving recorder data is that it is now possible to objectively analyze the factors that contribute to the occurrence of the crash, for example a driver's behavior and traffic environment. In previous studies, naturalistic driving data of near crashes and crashes were collected using GPS, acceleration sensors, steering sensors and CCD cameras which filmed the driver's forward view as well as the driver's face (Arai et al., 2001; Uchida et al., 2010). These data were analyzed to understand pre-crash causal and contributing factors (Dingus et al., 2006).

Several researchers have used driving recorder data to investigate the factors that influence the cause of crashes and near crashes, especially for car-to-pedestrian cases (Dingus et al., 2006; Matsui et al., 2011, 2013; Yuasa et al., 2013; Habibovic et al. 2013; Takanashi et al., 2015; Raksincharoensak et al., 2013). In their research, parameters such as vehicle speed, pedestrian walking speed, lateral and longitudinal distances to the pedestrian, and time-to-collision (TTC) were analyzed. Habibovic et al. (2013) analyzed 90 car-to-pedestrian near crashes collected from a naturalistic driving study conducted in Japan in order to identify contributing factors that lead to these incidents. Their analysis showed that drivers failed to recognize the presence of the pedestrian at intersections because several obstacles along the road obstructed the view of the drivers and/or their attention was on something else other than the pedestrian.

In contrast to pedestrian crashes, there are only a few research studies for car-to-cyclist crashes and near crashes using driving recorder data. Bicycles have a higher speed and rider behavioral patterns are different from pedestrians. Therefore, the mechanisms of car-to-cyclist crashes are also likely to be different from those in pedestrian crashes. In previous studies using driving recorders, cyclist crashes and near crashes were analyzed by using either data from a mix of all crash types (car-to-other vehicle, pedestrian, cyclist, roadside barriers and so on) (Dingus et al., 2006; Klauer et al., 2006; Cheng et al., 2010, Guo et al., 2010), or near crash data mixed with crash data (Lin et al., 2011; Chen et al., 2016; Sasaki et al. 2014; Tsutsumi et al. 2015), or only near crash

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data (Matsui et al., 2015, 2016). The driving recorder analyses enabled researchers to examine what type of factors (e.g. visibility and road type) affect driver's braking reaction in car-to-cyclist crashes (Chen et al., 2016), as well as to obtain detailed time-histories of the brake pedal operation and car velocity during the car-to-cyclist near crashes (Tsutsumi et al., 2015). This information is usually difficult to obtain from conventional crash investigation and analysis, and based on subjective information from driver or witness statements.

While the previous driving recorder studies of car-to-cyclist crashes and near crashes mentioned earlier have yielded some valuable insights into drivers' and cyclists' behaviors in general, the validity in using them to investigate the cause of the crash is questionable. One reason is that these previous studies on car-to-cyclist crashes using driving recorders regarded near crashes and actual crashes to be the same. For example, Matsui et al. (2015) investigated the relationship between TTC and the distance to a cyclist using car-to-cyclist near crashes in which the cyclist appeared in front of the car. They concluded that if the near crash videos contains the cyclists' behaviors, then the scenarios leading up to a car-to-cyclist crash could be estimated from these near crashes because they found that about 80% of cyclists involved in crashes on straight roads or at intersections cross the road in front of forward-moving cars. This percentage is almost the same as that in cases of near crashes. However, these previous studies did not consider that the car and cyclist may have different moving speeds and/or different avoidance behaviors for crash and near crash cases. In fact, an analysis using data from a mix of all crashes showed that there is a significant difference in driver reactions for crashes and near crashes (Guo et al., 2010). Thus, a direct comparison between the actual car-to-cyclist crashes and the near crashes is needed in order to explore the differences between them.

The purpose of this study is to examine the factors that differentiate car-to-cyclist crashes from near crashes and identify the causes of the crashes. The car-to-cyclist crashes and near crashes that were recorded on the cars' driving recorders were compared with each other. Our focus was on the near crashes and crashes where the car and cyclist met each other perpendicularly, hereby referred to as perpendicular crashes, because these frequently occur in Japan. The differences in the car and cyclist parameters such as velocity, distance and avoidance behavior was analyzed. From the results, the typical scenarios that cause car-to-cyclist crashes were discussed.

2. Methods

2.1. Data collection

In this study, various types of after-market driving recorders already installed in taxis were used. The driving recorders integrated a variety of sensors (e.g. cameras, 3-axis accelerometer and GPS) and stored 10–15 s of data about safety-critical events every time a strong longitudinal and/or lateral acceleration were recorded by the unit. Among the overall information collected by the driving recorder, time-histories of the braking pedal operation and car velocity as well as the video including road type and visual obstructions of driver's view were used.

The overall dataset, including approximately 3000 near crashes recorded during the period 2005–2010 from driving recorders installed in taxis, was compiled by Tokyo University of Agriculture and Technology (TUAT) (Kamata et al., 2006; Shino et al., 2008) and screened to obtain a smaller sample of events used in this study. The driving recorder data in TUAT database were classified into two event severities (i.e. crash and near crash) according to the definition proposed by the SHRP2 researcher dictionary for video reduction (SHRP2, 2016). For the car-to-cyclist crashes, a mix of 140 car–to-cyclist crashes recorded on driving recorders installed in taxis in Aichi prefecture as well as others from the TUAT database were used. In this study, because our focus was on perpendicular car-to-cyclist crashes and near crashes, there were only 47 crashes and 532 near crashes where the car and bicycle approach each other at 90° (bicycle crossing the path of the taxi). The selection of relevant cases was conducted by using the graphic user interface integrated in the TUAT database (Kamata et al., 2006) and by the authors' screening of the Aichi prefecture dataset.

Key information for the analysis were avoidance maneuvers as well as the appearance location and timing of a cyclist in the video so criteria were defined to obtain the crash and near-crash samples from the large raw dataset. Cases lacking acceleration information or those with poor-quality video recordings due to low resolution or poor orientation of the camera were removed.

2.2. Characteristics of crashes and near-crashes

The crashes (47 cases) and near crashes (532 cases) were first compared using information about road configuration, type of visual obstruction present in the surrounding area, and cyclist avoidance maneuver before the crash or near crash.

In order to analyze the road configuration where a crash or near crash occurred, the data were classified based on SHRP2 (SHRP2, 2016). The data were classified by whether the crash occurrence location is related to a junction or not. The junction-related and junction cases were further classified by number of lanes on the road on which car and cyclist travel. The non-junction cases were treated as "Not Int. (not intersection)".

2.3. Calculation of relative trajectory and TTC of cyclist from car

In order to study the factors that lead to crashes, information about the car's velocity and the position of the cyclist relative to the car were obtained. The car's velocity was derived directly from the output of the driving recorder. The position of the cyclist relative to the car was determined by analyzing the video. First, the horizon line and the vanishing point of the front view of the camera were defined. Then, the distances between the reference points in the video were calculated based on fixed objects present in the video such as a crosswalk on the road. In order to validate the calculated distance from the video analysis, the estimated vehicle-bicycle distance was also compared with the relative distance obtained by integrating the car velocity with time.

Time-to-collision (TTC) was used as a parameter to evaluate crash risk at various points in time before the crash. The TTC was calculated using the car velocity V and the distance D from the car to the point of crash (Fig. 1). For near crashes, since no actual crashes occurred, the point of crash was defined as the point where a potential impact with the cyclist would occur if no action was taken by the driver or the cyclist.

A typical velocity-time history of the car during the event is plotted in Fig. 2. The cyclist first appeared in the video at time t_a, and the driver started braking at time t_b. The car velocity and distance between the car and the cyclist at time t_a and t_b were defined as V_a, D_a, V_b, D_b, respectively. Therefore, TTC_a and TTC_b at time t_a and t_b was calculated as follows:

$$TTC_a = D_a/V_a \quad (1)$$

$$TTC_b = D_b/V_b. \quad (2)$$

The term t_b was defined as the timing when drivers performed sudden hard braking of 0.35–0.4 G, depending on the type of drive recorder. When approaching a small intersection with low visibility, drivers often predicted the danger. Throttle release and/or light brake applications were used to reduce speed in order to scan for potential threats on the roadsides and to avoid possible critical situations. In these cases, the velocity decreased during the time t_a and t_b. Note that Eqs. (1) and (2) calculate collision times given the vehicle continues at constant velocity.

The reaction time of the driver was also investigated using the equation $RT = t_b - t_a$, which represents the time from the cyclist's first