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The Dynamic Responses and Head Injury Correlations of Child Pedestrians Involved in Vehicle Accidents

Abstract

This study is aimed to investigate the correlations of impact conditions and dynamic responses with the injuries and injury severity of child pedestrians by accident reconstruction. For this purpose, the pedestrian accident cases were selected from Sweden and Germany with detailed information about injuries, accident cars, and accident environment. The selected accident cases were reconstructed using mathematical models of pedestrian and passenger car. The pedestrian models were generated based on the height, weight, and age of the pedestrian involved in accidents. The car models were built up based on the corresponding accident car. The impact speeds in simulations were defined based on the reported data. The calculated physical quantities were analyzed to find the correlation with injury outcomes registered in the accident database. The reconstruction approaches are discussed in terms of data collection, estimating vehicle impact speeds, pedestrian moving speeds and initial posture, secondary ground impact, validity of the mathematical models, as well as impact biomechanics.

Introduction

Each year, about 1.2 million people are killed in road vehicle traffic collisions and more than 50 million injured worldwide. Huge economic losses and serious consequences result from these traffic accidents [1]. The road users like pedestrians, cyclists, motorcycle riders are exposed to a high risk of injury, of which the pedestrians are the most vulnerable road users and account for a large part of traffic casualties in collisions with motor vehicles. The studies in Europe [2-4] indicated that the passenger cars are most commonly involved in pedestrian accidents. figure 1a shows a distribution of vehicle type in pedestrian accidents based on collected data from Swedish national accident database STRADA. The injury distribution according to different injury severity is shown in figure 1b.

During the past three decades significant reductions in pedestrian fatalities have been achieved in Europe [5] and the United States [6]. This tendency is mainly due to improved traffic planning in built-up areas. Other safety programs

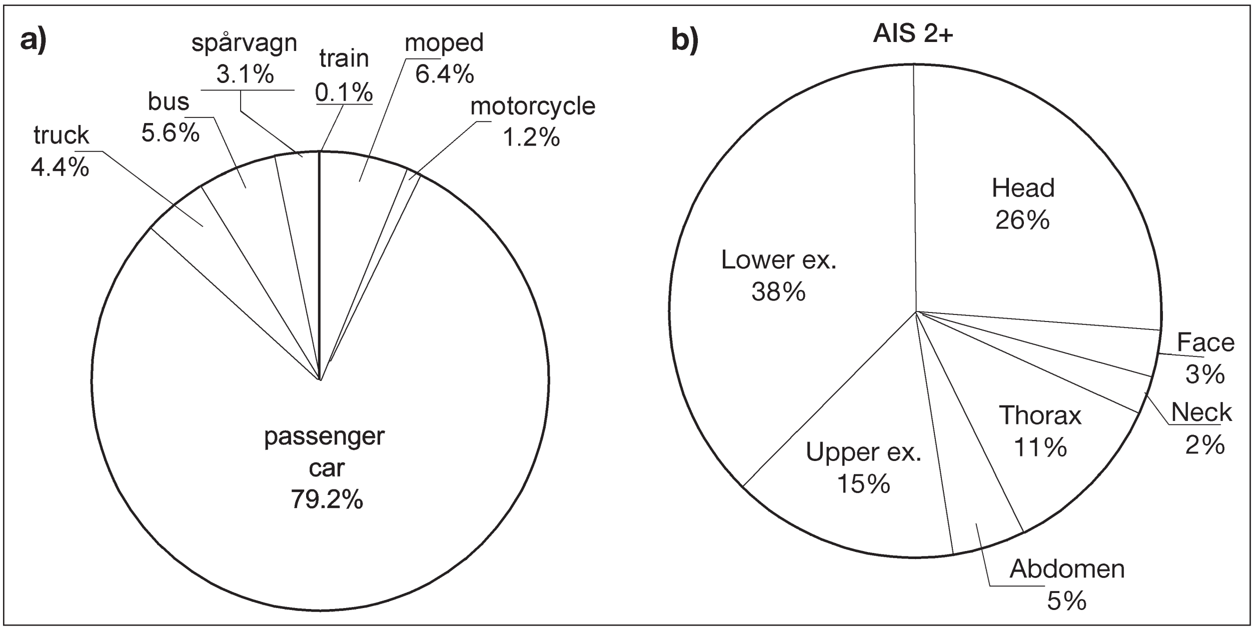

Fig. 1: (a) Involved vehicle type in pedestrian accident, and (b) Injury distribution in passenger car to pedestrian accidents

such as appropriate speed limits, drink driving control, education of young people could also contribute to the reduction of casualties. So far, there is not any statistical study to prove that injury reduction is caused by changes of car-front shape, but the findings from studies suggest that a potential benefit can be obtained from improvement of new vehicle designs which meet the EEVC requirements.

The pedestrian accidents in road vehicle traffic have been extensively investigated world-wide in the past four decades to find solutions for pedestrian protection from vehicle collisions. A study on improvement of car front design requires detailed information about the dynamic responses and injury biomechanics of pedestrians, such as the loads to body segments, and injury related parameters that are usually missing even impossible to acquire in an in-depth field investigation. In order to get better understanding of kinematics and injury related physical quantities associated with pedestrian response to vehicle impacts, a large number of studies havs been done by simulation or reconstruction of the collisions using post-mortem human subjects (PMHS) or mechanical/mathematical dummies. The correlation of pedestrian injuries observed in accidents with the biomechanical responses and injury related parameters has been determined by combining the knowledge from those studies.

This paper presents a study on pedestrian accidents with focus on detailed individual case analysis via accident reconstruction using the mathematical models. The objective of the study is to determine the correlations of impact conditions and dynamic responses with the injuries and injury severity of pedestrians from accident. The results were analyzed and the reconstruction approach in the study is discussed in terms of data collection, the basic variables, missed data elements, estimating vehicle impact speeds, pedestrian moving speeds and initial posture, secondary ground impact, validity of the mathematical models, as well as impact biomechanics.

In-Depth Accident Analysis

An ongoing study of pedestrian accidents is being carryied out in co-operation between Chalmers and Hannover. In Sweden 2 child pedestrian cases were collected and an in-depth study was conducted via accident reconstruction with mathematical models developed at Chalmers [7]. In Germany 69 child pedestrian accident cases were selected from the accident database GIDAS (German In-Depth Accident Study) documented by the Accident Research Unit at the Medical University of Hannover [8-9]. In the district of Hannover a representative sampling of accidents is carried out by order of the German Government (Federal Highway Research Institute BASt) in co-operation with the car manufacturers FAT [3]. For each collected case, complete information regarding pedestrians, vehicles, and crash environment was documented.

Injuries sustained by each pedestrian were coded either on the accident scene (if possible) or later in the hospital according to AIS 90 (AAAM, 1990). For a given body region which sustained more than one injury, only the single most severe AIS score was registered. The anthropometric data of the pedestrian such as age, gender, height, and weight were also documented in the hospital. Accident witnesses were investigated to obtain the accident information such as pedestrian posture, impact direction, etc. For the 69 children involved in the accidents, the initial posture at the moment of impact was determined as running, fast walking, walking or standing. figure 2 shows that half of the children were running but only 2% of the children were standing when they were hit by the vehicle. This is remarkable comparing to the situation of adult pedestrians. The accident data also showed that 87% of the children were impacted from the lateral direction.

The injury distribution of child pedestrian is shown in table 1. It was observed that the head and the lower extremities were the two most frequently

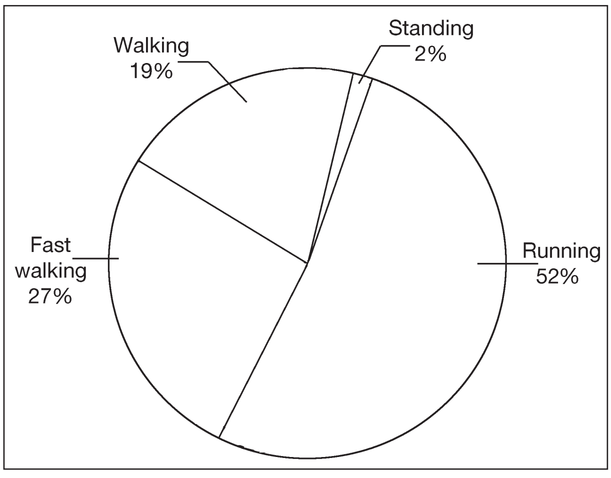

Fig. 2: Action of child pedestrian at the moment of impact

Body Region	AIS 1	AIS 2+	All Injuries
Head	25.8%	56.4%	33.1%
Neck	2.4%	0.0%	1.8%
Thorax	4.8%	7.7%	5.5%
Upper Extremities	23.4%	12.8%	20.9%
Abdomen	4.0%	0.0%	3.0%
Pelvis	11.3%	0.0%	8.6%
Lower Extremities	28.2%	23.1%	27.0%

Tab. 1: Injury distribution by body regions

injured body parts during the accidents. For AIS 1 minor injuries, head and lower extremity injuries accounted for 25.8% and 28.2% respectively. For AIS 2-6 injuries, head and lower extremity injuries accounted for 56.4% and 23.1% respectively.

The vehicles involved in the accidents were recorded with detailed information about passenger car makers, model, registration year, estimated impact speed. The selected cases were limited with accident car models introduced to the market after 1990. Thus these accidents reflect the most up-to-date child pedestrian accident characters. The deformation pattern, contact points on the car and characteristics of special traces on the road and on the car were measured and documented in a 3-dimensional x, y, z-coordinate system with reference to the longitudinal central line of vehicle. Pictures of impact location are documented and could be used for analysis. The final positions of the pedestrian, car and any other related features were also recorded. The collected data provided most important information to carry out the accident reconstructions.

In the present paper, 12 cases were presented to analyze pedestrian injury biomechanics and the correlation of impact conditions and biomechanical responses with the injury outcomes in the collisions.

Example Case 1: 7 Years Old Child-to-OPEL

Pre-Crash

A car-to-child pedestrian collision occurred on a secondary rural road in south Sweden. The accident car is OPEL Rekord Combi 1985 model. The driver claimed that he saw a group of children playing on the right side of the road from about 50 meters away (position A in figure 3a). When the car was approaching the group of children at speed about 70km/h, the driver lifted his foot from the accelerator as he noticed the potential risk. Then he began to brake slightly as the car was approaching the crossing. Suddenly a 7-year-old boy began running across the street when the car was arriving at position B. The driver braked hardly and manipulated the car to avoid an impact.

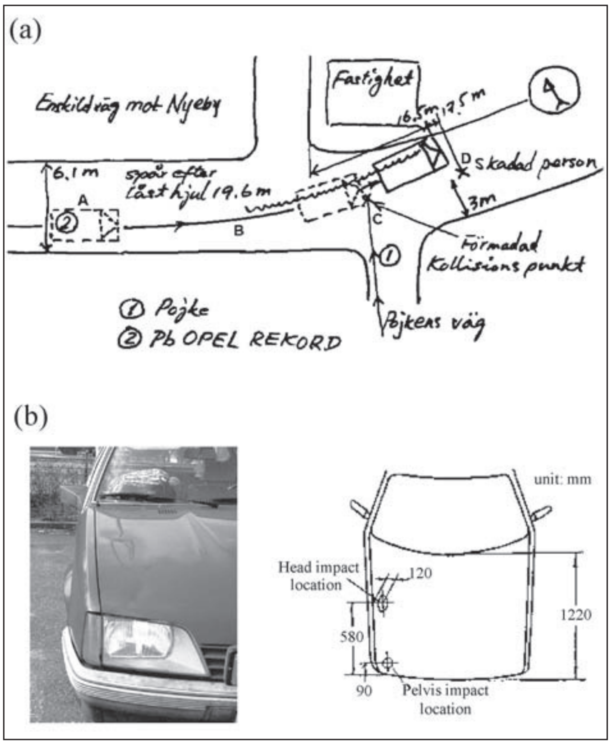

Fig. 3: Scheme of (a) accident scene, (b) the location of head and pelvis impact on hood top

Crash

The car, however, still hit the child by the right front corner at position C and at an estimated speed about 40–45km/h. The car stopped about 10 meters away from C, and threw the child to position D (figure 3a).

Post-Crash Data

The injuries of the child pedestrian were identified and registered in hospital. The child sustained unconsciousness due to the head-brain injuries: fracture left orbit (AIS 3), subdural hematoma left frontal lobe (GCS 5, GOS 2, and AIS 5). Except some slight outer skin injuries in the lower extremities, no other injuries were reported. After 7 weeks the child could stand up but not walk.

The damage of the accident car and interactions between the car and body segments of the child were determined based on the police report. The accident car suffered slight damage. The right headlight was broken. Two dents were found on the hood. The contact dents were visible on the leading edge of the hood and the hood top (figure 3b). The dent on the hood top was identified as the result of the head impact. It was about 580mm away from the hood edge and 120mm away from the right fender. Another dent caused by the pelvis impact, was about 90mm away from the hood leading edge. No evidence indicated the damage to the structures beneath the hood. The measured wrap around distance (WAD) was 1350mm. The throw distance was 14m from initial impact.

The available data are summarized in table 2 for reconstruction of the accident. It is necessary to mention here that some information for accident reconstruction is not possible to acquire from field investigation, such as the vehicle front stiffness, and kinematics of the pedestrian collision.

Example Case 2: 4 Years Old Child-to-OPEL Omega Combi 1994

Pre-Crash

A passenger car-to-child pedestrian accident happened in a residential area in Hannover, Germany. The accident car is an OPEL Omega Combi 1994 model. The car was-traveling on a street where several vehicles were parking along one side (figure 4a). A 4-year-old boy walked fast from position A to cross the street. Because of the parked car, the driver could not see the boy in advance. After the driver saw the boy, he braked hardly but still hit the boy. The impact speed was about 25km/h.

Crash

The car hit the child by the left front part at position B. The boy was thrown away and the rest position was C. The throw-out distance was about 600cm.

Post-Crash Data

The child sustained AIS 2 head injury, AIS 1 lower extremity injury. On the vehicle, scraps on the bumper and dents on the hood were found as shown in figure 4b.

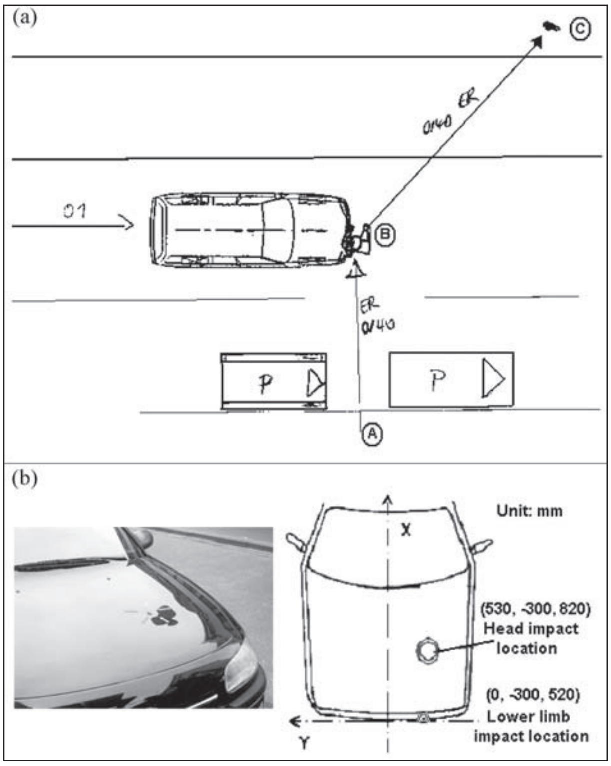

Fig. 4: Scheme of (a) accident scene, (b) Scraps and dents found on the accident vehicle

Pre-crash		Crash		Post-crash	
Vehicle		**Vehicle**		**Pedestrian**	
- Travel speed	estimated	- Impact speed	estimated	- Gender	Boy
- Pre-crash braking	yes	- Contact point	identified	- Age	7
Pedestrian		**Pedestrian**		- Height	estimated
- Initial posture	identified	- Kinematics	NA	- Weight	estimated
- Moving speed	estimated	**Ground impact**		**Injuries**	
- Orientation	identified	- Body contact	NA	- Injury patterns	identified
Road environment		**Throw distance**	measured	- Injury distribution	identified
- Road type	rural road	- Landing point	NA	- Severity	AIS, GCS, GOS
- Road surface	asphalt	- Sliding distance	estimated	- Cause of injury	determined
- Weather condition	fine	- Resting point	determined	**Vehicle**	
				- Damage (dents, scratch)	identified
				Field information	
				- Skid mark	measured

Tab. 2: Summary of accident data collection for reconstruction in case 1

Accident Reconstructions

The selected accident cases are reconstructed using pedestrian mathematical models and passenger car models.

The geometry of the child models was generated based on the height, weight, and age of the pedestrians involved in the accidents. The characteristics of child models were scaled from a validated adult pedestrian model [10-11].

The anthropometric data of the pedestrian models used in the reconstructions were summarized in table 3, which was based on the data from the accident analysis.

The vehicle was modeled by a group of ellipsoids in MADYMO. The geometry of the vehicle models was obtained from the production drawings of the cars that had the same make, model and series as those involved in the accidents. The mechanical properties of the car models were defined in terms of stiffness properties acquired from EuroNCAP sub-system tests. The impact speeds of the cars and the pedestrian moving speeds were estimated based on the accident data, considering the car braking skid marks on the road surface and the pedestrian moving postures before the impact.

The kinematics were simulated in the reconstructions of the selected accident cases. The injury parameters in head, chest, pelvis and lower extremities were calculated to evaluate the injury severities from the accidents. The correlations of the output parameters from simulations with the injuries described in the medical and accident report were analyzed. The threshold of brain injury parameters, such as HIC and angular acceleration, was discussed based on reconstruction results.

The Set-up of Reconstruction Models

The reconstruction models were built up based on the complete information about the accident of each case. The configuration of the case 1 reconstruction model is described as an example as follows.

A mathematical vehicle model was developed based on the schematic drawing of OPEL Rekord Combi. The vehicle front structures were presented by four ellipsoids including lower bumper, bumper, hood edge and hood top as well. Several plans and ellipsoids were assigned to describe the outer surface and wheels. The force-deformation properties of the front structures were obtained from the sub-system test results of EuroNCAP. The friction coefficient between the wheels and road surface was assumed to be 0.7. The diving angle was assumed as 3 degrees. The steering effect was also simulated by defining an angular velocity of 1 rad/sec2 about z-axis.

A 7-year-old child model was developed by using the scaling method from a validated adult model [10-11]. The initial posture was adjusted to be running in the direction perpendicular to the car moving direction. The running speed was estimated at about 10km/h. The friction coefficient between child body segments and road surface was based on empirical data, and was set at 0.6.

Results

Kinematics

Overall Kinematics of Child Pedestrian

Taking case 1 for example, figure 5 shows the overall trajectory of the 7-year-old child during the impact. The estimated vehicle travel speed was about 65-70km/h at the initial position (figure 3a),

Case No.	1	2	3	4	5	6	7	8	9	10	11	12
Age	7	9	12	4	7	6	6	6	5	6	4	8
Height (mm)	1230	1300	1200	1100	1200	1130	1200	1150	1200	1260	1100	1280
Weight (kg)	25	30.7	45	18	31	22	18	12	25	31	17	25

Tab. 3: Anthropometric data

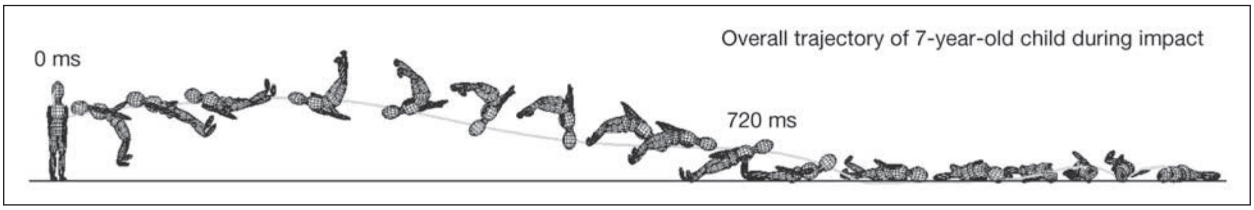

Fig. 5: Overall trajectory of 7-year-old child in collision with passenger car

and around 40km/h at the impact position. The simulated braking distance from the crossing to the vehicle rest position was about 16.1m (accident: 16.5m), and the child total throw distance was around 13.5m (accident: 14m). Both were close to the information collected by the police.

Head impact occurs at around 60ms after the initial contact. The head impact location is 570mm (accident: 580mm) away from the hood leading edge and 120mm (accident: 120mm) away from the right fender.

Head Impact Conditions

The child head impact conditions to the car front were determined for each case in terms of head impact location, resultant impact velocity relative to the car, head impact angle relative to the horizontal, as well as timing of head impact.

The contact location of the head on the vehicle could be defined by the wrap-around distance (WAD) along the car-front surface. Results from accident reconstructions show that the WAD ranged from 93 to 119cm (table 4). This WAD would usually make the head to hit the hood top. The WAD is greatly influenced by the pedestrian height. To eliminate the influence of the pedestrian body size, the ratio of the WAD to the pedestrian height was calculated. The statistics analysis shows that the average value of WAD to the pedestrian height ratio is 0.927 with a standard deviation of 0.072. Usually, in the child pedestrian accident, the WAD could be regarded as the length from the head centre to the foot.

4 reconstructed accident cases were selected since the children involved had the same height of 120cm. figure 6 illustrates the time history of the head resultant velocities of these 4 child pedestrians. For children at the height of 120cm, the head impact timing varies from 56ms to 83ms (figure 6). The results indicated that the head impact timing varied in a wide range due to vehicle speed.

The head impact speed appears to be proportional to the vehicle impact speed as shown in figure 7. Normally, the child head impact speed is lower than the vehicle travel speed at the moment of impact.

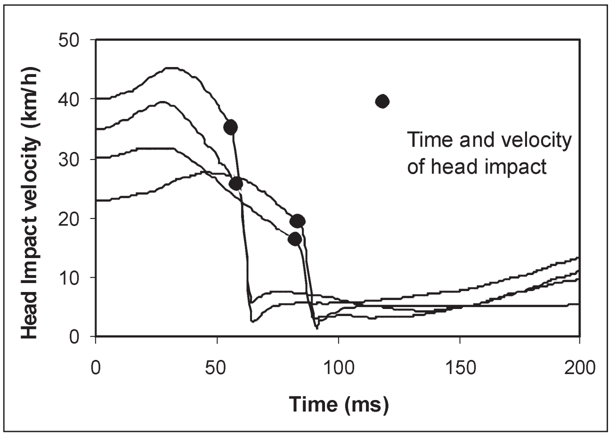

Fig. 6: The time history of head resultant velocity with respect to car front

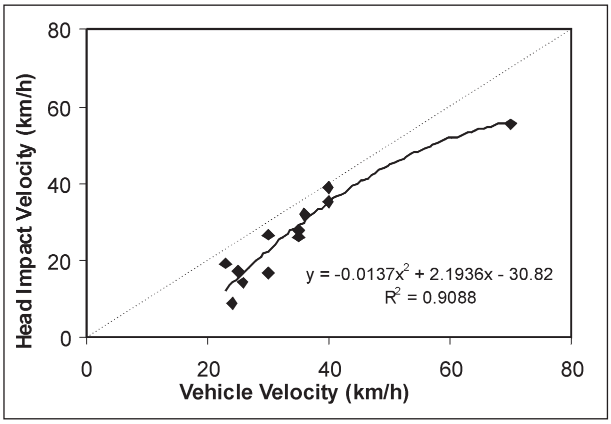

Fig. 7: Relationship between head impact speed and vehicle speed

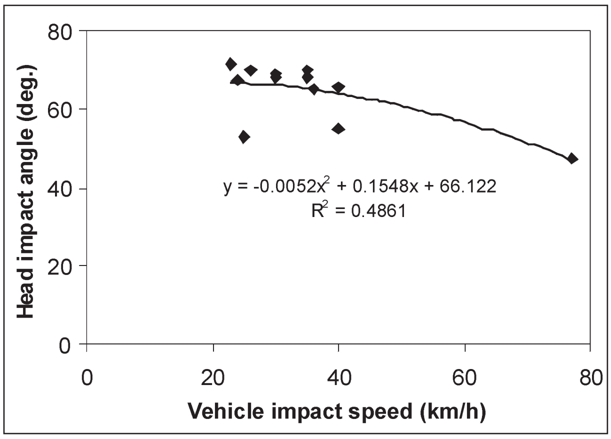

Fig. 8: Relationship between the vehicle impact speed and head impact angle

Case No.	1	2	3	4	5	6	7	8	9	10	11	12
Height (mm)	1230	1300	1200	1100	1200	1130	1200	1150	1200	1260	1100	1280
WAD_R (mm)	1306	1364	1000	970	1090	1030	1040	1120	1110	1190	930	1180
WAD_R/Height	1.06	1.05	0.83	0.88	0.91	0.91	0.87	0.97	0.93	0.94	0.85	0.92

Tab. 4: Correlation of WAD distance with child pedestrian height

The head impact angle could be greatly influenced by several factors such as the pedestrian height, hood edge height, hood angle and impact speed. A statistics analysis of the simulation results shows that the average impact angle is 64° with a standard deviation of 7.8°. The individual contribution of each factor to the head impact angle should be investigated using more detailed parameter studies. figure 8 shows the relationship between head impact angle and vehicle velocity. The results showed that the head impact angle usually decreases with the increasing of vehicle impact speed.

Calculated Injury Parameters

The head injury risks were evaluated by calculating HIC, head angular acceleration and head angular velocity. Other calculated injury parameters, such as 3-ms clips of resultant thorax and pelvis accelerations, femur and tibia lateral accelerations, were summarized in table 5.

The relative importance of ground and vehicle in causing the head injury is investigated in terms of HIC ratio β which is defined as follows:

$$\beta_{HIC} = \frac{HIC_{car-impact}}{HIC_{ground-impact}} \quad (1)$$

table 5 shows that during the second impact, it could be the head or other body parts that first land on the ground. If the head first lands on the ground, there is a high probability that the HIC ratio would be smaller than 1.

The relationship between head injury severity and vehicle impact speed is shown in figure 9. A nonlinear correlation is achieved by a second-order polynomial curve.

The correlation between the head injury severities in the accidents and the calculated injury parameters was investigated. Table 5 shows that the HIC value could be a good indicator for child pedestrian head injury. However, to establish the correlation of head injury risk with the HIC value, more accident cases are needed.

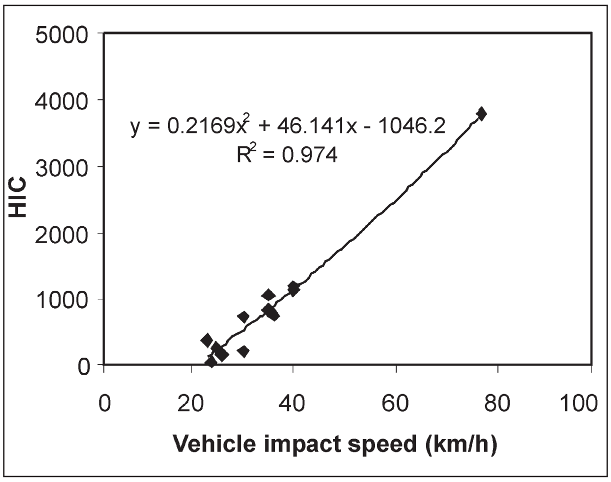

Fig. 9: Correlation of vehicle impact speed and HIC

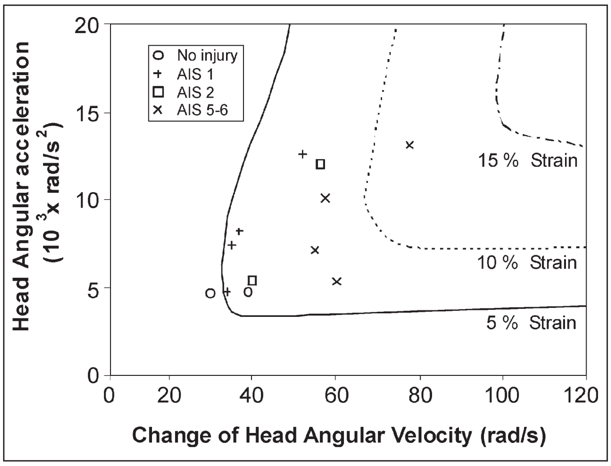

Fig. 10: Correlation of head injury severity and head angular motion

Case No.	1	2	3	4	5	6	7	8	9	10	11	12
Vehicle speed (km/h)	40	36	23	35	30	24	35	77	40	26	25	30
$HIC_{car-impact}$	1147	764	367	1041	227	58	851	3788	1182	166	263	725
HIC ratio	1.23	1.10	1.11	1.03	0.51	0.10	1.08	0.77	1.14	0.89	0.33	0.99
Head ang. acc. (rad/s2)	7135	5293	8200	12003	4755	4770	12620	13060	10075	4679	5435	7384
Head ang. vel. (rad/s)	55	60	37	56	39	34	52	78	58	30	40	35
Thorax acc. (g)	43.9	24.8	53	46	33	31	45	144	57	18	31	35
Pelvis acc. (g)	104.7	62.0	58	93	59	67	90	271	162	50	82	83
Femur lateral acc. (g)	107.1	96.9	61	100	128	84	94	709	144	71	95	91
Tibia lateral acc. (g)	95.2	101.8	69	105	146	93	101	877	154	97	110	93
Landing body part	Foot	Foot	Head	Foot	Foot	Head	Foot	Head	Foot	Head	Head	Head
Head injury (MAIS)	5	5	1	2	0	1	1	6	5	0	2	1

Tab. 5: Calculated injury parameters from accident reconstructions

In the accident, the head of the pedestrian usually had a rotational motion. The skull will stop rotation quickly when the head hits the stiff bonnet. However, due to inertia the brain will continue its movement and rotate relative to the skull, which causes a strain of the brain. figure 10 shows the tolerance curves for 5% strain, below which the should have no axonal injury, and 10% critical strain, below which mild injury could be expected and above which DAI could be expected [12]. figure 10 shows most AIS 1 and none head injuries are below or around the 5% strain curve. The AIS 5-6 head injuries are around 10% strain curve. The results show that the rotational motion is another important indicator for the head injury.

Discussion and Conclusions

Pedestrian accident reconstruction is an important approach in the crash safety field for investigation of vehicle-pedestrian impacts. The dynamics, injury biomechanics of the pedestrian collisions are somewhat different from that of vehicle-vehicle impacts. In this study efforts have been made to find the correlation of the calculated biomechanical responses of pedestrian body segments with the corresponding injuries observed in accidents, as shown in the calculated results from reconstructions of children pedestrian accidents. The reliability of the findings from accident reconstructions is dependent on the quality of data sources, including information about three aspects: impacting vehicles, pedestrians, and road traffic environment.

Data Sources and the Basic Variables

The accident data used in these studies were collected from hospital clinical record and police report, which contributed to form national databases. This study was carried out based on the databases for acquisition of detailed information about causation and occurrence of accidents, injury patterns, causation and distribution of the injuries. The documented information forms firm background for the in-depth study on impact biomechnics and injury correlations of child pedestrians in vehicle collisions.

Estimating Vehicle Impact Speeds

The vehicle impact speed is one of the most important issues to investigate the pedestrian impact responses and injury biomechanics. There are various approaches to estimate the vehicle speed at the moment of the collision. In the present study the following techniques were used to estimate the vehicle impact speeds based on available accident data such as skid marks and pedestrian throwing distance [4]. The vehicle impact speed can be determined also by simulation of vehicle and pedestrian motions.

Vehicle Speed Based on Skid Marks

Calculation of vehicle speed by using skid marks is the most common way in pedestrian collision analysis, in the case of accident vehicle skidded after an emergency braking. The length s of the skid marks can be measured in field investigations. For determining the passenger car speed in example case 1, the skid marks were registered about 11–14.5m long. The possible car impact speeds V_i are calculated using equation as follows:

$$V_i = \sqrt{2g\mu s} \qquad (2)$$

Where the μ = 0.6 ~ 0.7, the V_i = 41 ~ 44km/h. It is necessary to point out that there could be some difference of the calculated speed from the speed in real world accident due to the effect of pedestrian mass and road surface conditions.

Vehicle Speed Based on Pedestrian Throw Distance

The skid marks are not always available in accident field. One of the reasons is due to the increasing use of anti-lock brake systems, so skid marks are less common. The pedestrian's total throw distance is another indicator of the speed of the vehicle at impact. Estimating vehicle speed by pedestrian throw distance is thus becoming more important in accident investigations. The vehicle impact speed can be estimated by simulation of the vehicle and pedestrian motions.

Pedestrian Initial Posture and Moving Speeds

In the real world vehicle-pedestrian accidents the initial posture of a pedestrian at an impact is varied in different motion attitude. Therefore an appropriate initial position should be investigated and defined for reconstruction of the pedestrian accidents. According to the present study, the child pedestrian initial posture in an accident is summarized as follows.

- In car-pedestrian accidents, the pedestrians are often struck from the side by the front structure of a vehicle when crossing a street. In this study, it was found that in 87% of the cases the pedestrians were hit from the side.
- The majority of 98% of the child pedestrians are in motion during impact, either walking or running. This indicated a remarkable difference from the study on initial posture of pedestrians in all age groups, of which 79% are in motion [13].
- For the walking position, it was proposed to take into account the leg orientation. During the pedestrian impact the kinematics and dynamic loading of the pedestrian are not the same if you have the left leg forward or the right leg forward.
- The impact responses and injury outcomes are significantly affected by the initial postures and the orientation of body segments.

The moving speed is another important variable to define in accident reconstruction. The child normal crossing speeds were established as 1.5m/second to 2m/second, which are recommended to be used in present study.

Secondary Ground Impact

In reconstruction results the HIC values were calculated in both first contact with the car and second contact with the road surface. In the 6 cases it is the head landing on the ground first during secondary impact. In the 6 cases it was other body parts landing on the ground first. It is usual that the HIC value in contact with the car front is lager than that in the second ground impact without the head landing on the ground first. The reverse is the case for the second ground impact with the head contacting the ground first. It indicated that the contact modes in secondary ground impact are complicated, which could be dependent to the vehicle front shape, impact velocity, and body size.

Validity of Mathematical Models

There are large differences between child and adult due to the variability of body size, mass distribution, characteristics of the developing body structures, and injury tolerance levels. The child models can be developed using available anthropometry data and existing software such as the MADYMO-GEBOD program, according to age, body height and/or body weight of the desired human model. However, limited knowledge is available for the characteristics of the developing body structures such as head, vertebra column and lower extremities of children. In the present study, a scaling method was used to develop the multi-body mathematical models [11].

The joints properties and contact stiffness of body segments are the essential input data for the models. The lateral flexion properties of neck, thoracic, lumbar, hip, knee and ankle joints were considered as the key issues for the dynamic responses of the child pedestrians involved in traffic accidents, because the majority of child victims are struck from side by vehicles. Based on the analysis of the behavior of the functional unit for the lumbar vertebrae and the knee joints under lateral flexion mode, the simplified joint model was developed to derive the scale factors of lumbar vertebra and knee joints.

For the lateral contact stiffness of long bones, the three-point bending model was used to calculate the scale factors from adult data. Without geometric data for long bones, it was assumed that the outer diameter of long bones is proportional to the circumference of the corresponding body part. For example, the diameter of tibia bone is based on the circumference of lower leg. It was found that the contact stiffness of a long bone depends on the cross-section, length and the elastic modules of the bone as well. The scale factors for the thorax and head were adopted from the available biomechanical study, respectively.

Child accident reconstruction is a feasible way to evaluate the effectiveness of the scaled children models. The reconstructions provided results for the overall motions of pedestrians, the throwing distances, the head linear and angular accelerations, HIC, the head impact velocities and angles, the head contact locations and timing on the car front structures. The calculated head angular accelerations are associated with brain injuries and within the reported brain injury tolerance corridor (figure 10). The results of accident reconstructions indicated the capability of the scaled models to predict the dynamic responses and injury severities of child pedestrians under impact loading.

Impact Biomechanics

Accident reconstructions by using mathematical models are the most efficient way to find the correlation of the injuries with physical parameters which resulted in the body damages in an accident.

It was found that the injury distribution of pedestrians varies with the body size. For the children under 6 years old, the chest and pelvis areas are exposed to high injury risks and the older children sustain more severe injury in head and lower extremities.

In the 9-year-old child case the HIC was 764 lower than the proposed tolerance level, however, head angular acceleration was above the proposed tolerance level. This correlated to the fact that this 9-year-old child also suffered the severe brain injury without skull fracture.

The HIC and brain strain caused by rotational motion are two important measurements of the head injury. The suitable threshold for head-brain injuries should be further investigated by collecting more accident data with very detailed information about causation of accidents and injuries.

Conclusions

Head injury risk in child pedestrian accident was examined based on accident investigation and reconstructions. The results showed that the head is most frequently and severely injured in car to child pedestrian accidents.

The head impact conditions such as impact velocity, impact timing and angle, wrap around distance are mainly dependent on the car front shapes, and size of the child pedestrian.

The head injuries caused by car front structures were usually more severe than those caused by the secondary ground impact.

The impact velocity and car front structures have a significant influence on the kinematics and injury severity of the child pedestrian head. By limiting the vehicle speed and improving the car front design, the head injury severity of the child pedestrian could be reduced.

The dynamic responses and injury parameters from accident reconstructions would provide complement knowledge to develop safety counter-measures and protection devices.

The using of well documented real accidents as given by GIDAS allows a good possibility for further development of computerized human models for simulation and accident reconstruction.

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