Research Article

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The Mechanics of a Pedestrian Run Over by A Motor Vehicle

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ABSTRACT

In road accidents, there are frequently incidents in which a person is hit by a vehicle and then run over or people who are lying on the road who are run over (without prior collision). Chest injuries are the most severe injuries, especially intrathoracic organ injuries; these are caused by a wheel rolling over the body. For the safety development of cars, these events are very rare (< 0.1 %) and therefore do not require mandatory measures. However, these incidents are often processed with forensic expertise. In this respect, knowledge of kinematics, mechanics and injury analysis are important.

In 1975, the author wrote a diploma thesis that deals with the detailed technical mechanism of running over a person lying on the road; this work has not been published to date. Nevertheless, there have been repeated individual enquiries prompting the need for publication at the present time.

The body of the pedestrian must be seen in mechanical strength as a rectangular compressible body with varying stiffness and flexible body segments. Characteristic end positions and distance-time correlations were found in the tests when the vehicle was run over at speeds of 30 and 50 kph. The most important influencing factor can be considered to be the crossing point on the body. The maximum movement of the body in driving direction of the wheel occurred when the thorax was run over and was significantly greater compared to when the head was run over; it was also greater with a braking wheel than with an unbraked wheel.

Keywords
Pedestrians, Run over, Road accident, Injury mechanics.

Introduction
In 1975, the author wrote a diploma thesis [1] at the Institute of Automotive Engineering at the Technical University of Berlin, which remains unpublished; the work examined the detailed technical mechanism of running over a person lying on the road. There have been repeated enquiries about the need for publication at the present time. This article is subject to this work, based on a literature review and real accident simulations with dummies lying on the road surface.

If one looks at the investigations carried out in the automotive industry in recent years to achieve the greatest possible safety in road traffic, we can see that these were primarily focussed on the occupants of cars and lorries as well as external road users such as pedestrians and cyclists, and that this has resulted in a very high level of protection against injuries in road accidents. In addition to these dominant accident types, there are also accidents in which the origin and sequence of events are special and rare; these types often present many difficulties in the investigation and search for causes due to a lack of knowledge and minimal experience in technical accident reconstruction. Accidents involving people being driven over, as a result of a pedestrian collision or a person already lying on the roadway (either with suicidal intent or under the influence of alcohol) should be emphasised here. If a vehicle drives over the body of a person with at least one wheel, this is referred to as 'run over' [2].

As this type of 'run over' accident occurs very rarely, studies in this area are also hard to find. They were more common in the early 1950s to 1970s, due to the relatively high ground clearance of vehicle underbodies and the relatively high position of the bumpers. As a result, incidents involving lorries running over pedestrians are particularly featured and are still common today, especially when lorries are turning right and cyclists collide with the side of a vehicle. The risk of a run over is still present with box-shaped vehicles such as lorries, especially construction vehicles and vehicles with high ground clearance. This type of incident is rare in modern cars with integrated bumpers and low vehicle skirts, so that statistically, runovers do not occur frequently, but occasionally after collisions with pedestrians and cyclists. The GIDAS accident surveys show a representative proportion of runovers of 0.14% n = 77 pedestrians in a total number of accidents with personal injury for the Hannover Region survey area for the years 1998 to 2022 (n = 54054 injured persons) [3].

For example, whether a pedestrian is thrown after a collision onto the vehicle or away from the vehicle onto the roadway and thus secondarily run over, depends not only on the ratio of bumper height to body centre of gravity height but also on the deceleration of the vehicle (unbraked). Hence, children and SUVs and vans are more commonly involved. Serious injuries are caused by a wheel rolling over a body; Voigt [4] mentions chest injuries in particular, describing intrathoracic organ injuries that occur between the rotating wheel and the base due to thoracic compression. Aortic ruptures are also common, as the heart is typically pushed into the thoracic cavity and the aorta is pulled. Because of the pressure on the thorax, profile marks can also be found on clothing due to the rolling wheel. Fractures of the thorax are often characterised by rib fractures and there are considerable dislocations of the bone fragments. In addition to the effect of the wheel, grinding, rolling and twisting movements can also cause a variety of injuries to the body due to the strong compression between the wheel and the road surface, mentioned by Buhtz [5]. The type and intensity of injuries is influenced not only by the wheel width and the load of the vehicle resting on the axle, but also significantly by the age of the victim and the elasticity of the skeletal system. Serial rib fractures are particularly common in older people, while young people may even suffer no bone injuries. Runovers of the legs are characterised by massive force and have a wide-ranging impact, with crushing and shearing effects, usually with severe bleeding into the muscle tissue. Buhtz points out that the right side of the body is predominantly affected by rib fractures, lung ruptures and liver shattering; this makes it likely that the compressive effect from the wheels of vehicles travelling on the right and people lying on the right-hand side of the road primarily affect the right upper abdomen and half of the chest.

More recent studies also newer one i.e. Fuchs [6] also show typical characteristics of injuries sustained by victims who are run over; these include frequent descriptions of broad contusions, décollement injuries (= avulsion), skin flaps that open in the direction of travel, compression injuries to internal organs and the spine, as well as massive abrasions. In her dissertation on the subject of runovers, forensic pathologist M. Lorenz [7] demonstrated that the head and legs are particularly commonly injured regions (Figure 1).

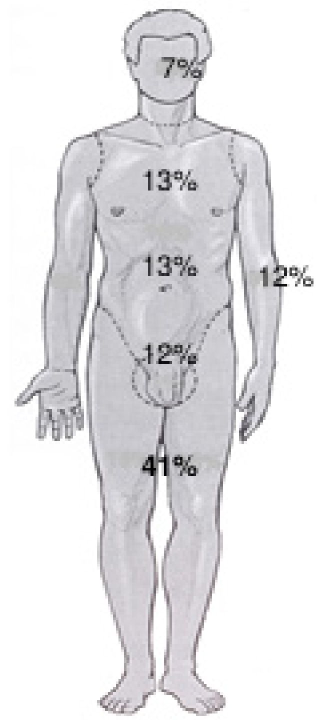

Figure 1: Injured body regions after accidents in which a person is run over, involving cars, lorries, tractors etc. [7] (85 patients, 1996 to 2005, Münster Hospital).

She states a mortality rate of 9%, with the cause of death mostly involving the thoracoabdominal region after a victim is run over at the chest.

In summary, the literature study shows few cases involving a run over victim. These are largely isolated cases and statistical significance appears negligible. However, these individual cases are particularly serious in terms of the type and severity of injury and can be found in the forensic literature. In forensic expert practice, analysis of runover injuries require expertise in traumatology. This is not taken into account in official accident statistics in Germany [8].

Few articles in the scientific literature address the detailed mechanics and kinematics of the process of a person being run over. Only Kassai [9] dealt with the subject from a scientific perspective in the early days of automotive development. In their work on new findings on limiting the collision speed of real pedestrian accidents, Harder et al. [10] cited not only the kinematics of the movement of a pedestrian colliding with a car but also the findings on runovers resulting from the Berlin study, albeit in very brief form. Hörz [11] described a calculation approach in a court expert report in 1972, using Kassai's study as a basis. He visualised the human body as a rod and allowed the impact force of the wheel to act with a lever arm in relation to the body's centre of gravity.

Other studies of runover accidents can be found only in the field of forensic medicine and deal almost exclusively with characteristic accident traces and detailed injury patterns, often as so-called case studies. Publications by Laves [12] and Nussbaumer [13] should be mentioned here. Nussbaumer in particular collected 73 cases of runovers in the Swiss canton of Zurich in the post-war years from 1946 to 1957. In his dissertation published in 1960, he described not only the detailed injuries found but also their accident history and attempted to describe the mechanics. He found that there was no significant shift in position when a head was run over. He found injuries in the chest area and head injuries occurred with almost the same frequency. The mechanism of the runover causing the injury is made up of several factors, such as compression, rolling, turning, dragging and finally sliding over the body; a vehicle or wheel exerts both pressure and thrust on a body.

Kassai prepared a physical and mathematical treatise on the mechanism that takes place between a wheel and an object (Figure 2).

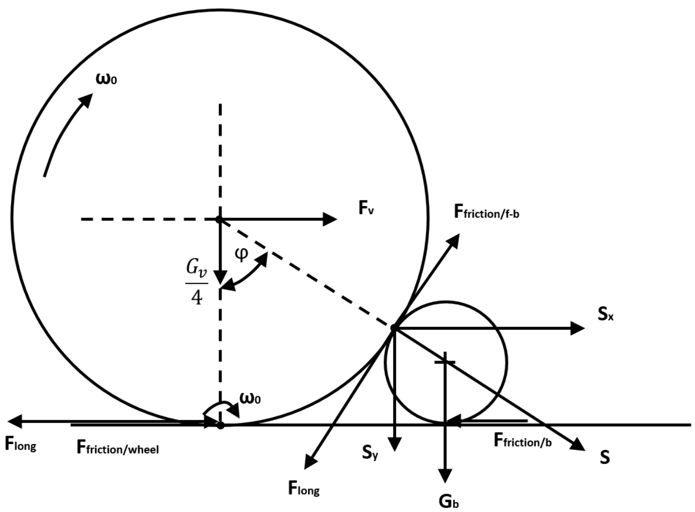

Figure 2: Mechanics of the runover process according to Kassai [9].

Study Objective

Knowledge of the course of an accident, the sequence of movements and the injury mechanisms is a prerequisite for establishing laws and minimising the severity of injuries through design measures on vehicles. In forensic expert reports, it is also necessary to deduce the speed and impact configuration from the final position of a victim on a road. Tyre marks are not always found on clothing or on the skin's surface. As a rule, a detailed injury pattern is used to explain statements about the mechanics and accident that took place, using the theories of Kassai and Hörz, among others. However, these theories should be viewed with scepticism, as they are based on both hypotheses and on inferences from injury patterns. Comparing running over a body with a running over a rigid object such as a beam at a height of half the wheel diameter does not correspond to reality. The human body is not a cylindrical single-rod model in cross-section, nor can it be explained as a single-rod model in the longitudinal axis; in addition, friction of a body lying on a roadway also plays a major role in resulting movement due to being run over and entrainment as a result of the rolling action on the body. The usual calculations for accident reconstruction with the aid of classic impact models are not applicable to runover processes.

The aim of this study was therefore to explain the real motion sequence of the runover process or, more precisely, the runover process of a person lying on the roadway and to understand the mechanics of this scientifically. The main parameters to be investigated were runover speed, wheel diameter, braking behaviour, runover point on the body and the angle of approach of the body to the direction of travel. As there are contradictory views regarding the sliding direction of movement of the person being run over, the question of whether the wheel rolling over the body pushes the body in or against the rolling direction also had to be clarified. Another objective was to investigate whether the characteristic injuries of a runover mentioned in the literature also occur in simulated dummy tests and what conclusions these examples provide.

To support and validate the results, runover tests were carried out with dummies and real vehicles to clarify the movement behaviour, as dummy tests generally provide a good correlation between real and simulated accidents [14].

Methodology of the Tests

The tests were planned with reference to the frequent points of impact found in the literature; 'head and thorax' were selected as crossing points of a person lying on the roadway at right angles to the car's direction of travel, as these are described particularly frequently in the literature.

Two test vehicles (Figure 3) with different tyre sizes and different underbody clearance (distance between body and ground) were selected as assumed influencing parameters:

- Transporter VW T1 with 14' tyres, ground clearance 25 cm
- Renault R4 car with 13' tyres, ground clearance 17.5 cm

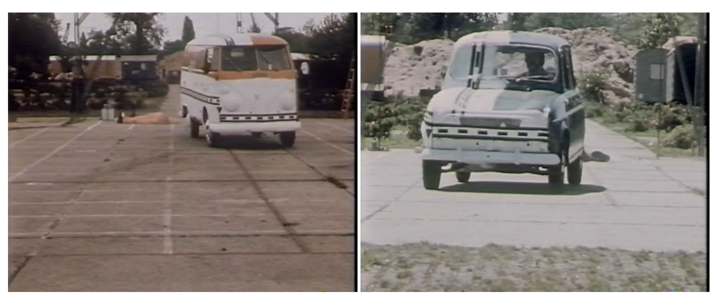

Figure 3: The test vehicles, a VW T1 and a Renault R4.

Nowadays, vehicles (Figure 4) can still be found with comparable ground clearance, so that the results can still be critically applied to current models. It should also be noted that some modern vehicles are equipped with height-adjustable air suspension systems and that common SUVs and vans today also have higher ground clearance. Ground clearance also depends on other factors such as tyres, technical equipment, load, etc.

Figure 4: Comparison vehicles, a VW T6 (2016 model) with approx. 25 cm ground clearance and a VW Polo (2017 model) with approx. 17 cm ground clearance.

An anthropometric manikin was selected as the person to be run over: 50% male humanoid 572 Pedestrian Dummy with the weight 75 kg and 175 cm height.
Two speeds were used, 30 and 50 kph respectively.
This resulted in a total of 16 trials, with 8 trials for each vehicle,
VW Bus T1:

- unbraked / head overrun / low speed
- unbraked / head overrun / high speed
- unbraked / Thorax overrun / low speed
- unbraked / Thorax overrun / high speed
- braked / head overrun / low speed
- braked / head crossing / high speed
- braked / thorax overrun / low speed
- braked / thorax overrun / high speed

Renault R4:

- analogous to the list for the VW bus

In order to determine the extent to which the human body can be regarded as a rigid mechanical model, 2 tests were carried out using a beam. This had the weight and length of the dummy.

The dummy was placed on the ground in a supine position at right angles to the direction of travel (Figure 5). Before the actual tests, the crossing point was calibrated by driving over it several times and indicated to the driver with a mark on the windscreen so that the body was driven over almost precisely. The speed was maintained by means of a speedometer display and light barrier measurement. The dummy's entire body was marked with white paint so that scuff marks and scratches were visible. The clothing was changed after each test. Marks from previous tests were therefore not included in the analysis.

Figure 5: Place the dummy in the supine position at right angles to the direction of travel.

Tests were recorded using high-speed cameras (LOCAM + PHOTOSONIC 250 images/second plus BOLEX 64 images/second). Perspectives were from the side, from the front and from above. In addition, a synchronised drum with a constant 15 revolutions per minute was set up; this allowed film recordings to be evaluated synchronously.

The final positions of the vehicle, the final position of the person and vehicle and pedestrian damage were photographed and measured, and the longitudinal and lateral distances (x, y) from the dummy's original position were measured.

In all tests, the dummy had the supine position as its initial position, as according to Nussbaumer ‘this stable position’ is always found in reality, so that this position was also used as the initial position in the tests.
The following measured values were recorded:

- Movement of the head, thorax, lower extremities
- Right and left in x and y direction
- Angle of rotation of the longitudinal body axis of corresponding body regions
- Vehicle movement in x-direction
- Angle of rotation of the wheel
- Wheel lift in cm
- Dummy lift in cm
- Angle of rotation around the longitudinal body axis of the corresponding body regions
- Movement characteristics of vehicle and pedestrian, such as start of movement, end of movement, wheel side deflection, change in camber.

Values were presented in diagrams as distance-time curves, then differentiated twice to determine the corresponding velocity-time curves and also the acceleration-time curves. The characteristic maximum values were tabulated and are discussed here.

Results

Kinematics of the runover

There are characteristic tendencies in the runover kinematics that reveal a dependence on the crossing point, which can be regarded as the most important influencing parameter.

The difference between the braked and the unbraked wheel is also important. It is noticeable that the maximum movement of the body in the x-direction of the braked test is greater than that of the unbraked test and there is a difference in the head to thorax crossing point.

After a tyre makes contact with the head, the thorax begins to move in the same direction only after 20 ms. The start of the division of the distance-time function curves begins at the point where the wheel comes free from the body and where the thorax begins to move in the same direction. This can be observed at each of the selected travelling speeds. In contrast, a movement of the entire body without a pronounced rotational movement of the longitudinal axis of the body can be observed at the thorax crossing point.

A striking feature is the lateral movement of the head around the vertical axis, i.e. the head moves 'to the side' of the head at the crossing point with the unbraked wheel, but not as quickly as with the unbraked wheel, as the wheel is still rolling, which results in a flatter increase in the displacement function. The maximum value of the angle is 90 to 100 degrees, due to the rather rectangular shape of the human head. Once the wheel is free from the head, the amplitude of movement decreases and the head straightens up again.

When a vehicle travels over the thorax, there are no rotational movements around the body's vertical axis. The wheel swings up and rolls over the thoracic body. In the braked case, the body is still slightly displaced in the rolling direction on the road, but then is also rolled over.

The kinematic findings are described in detail below.

Head as the Crossing Point

If a head is run over, the following characteristic movement sequence (Figure 6) always occurs:

Video Sequence of a Head Being Run Over, Lateral View:

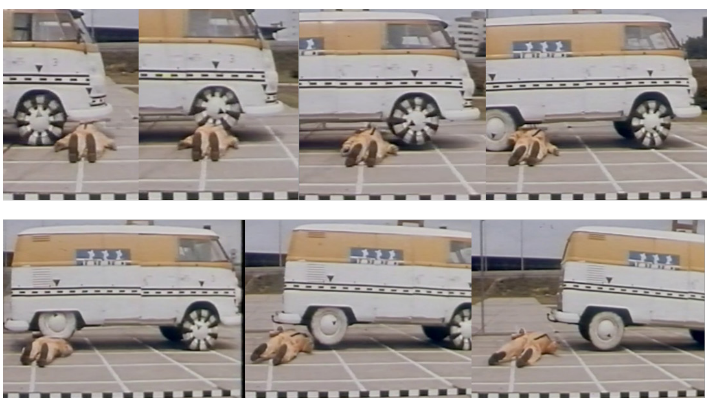

Figure 6: High-speed sequences, total 5 sec. video excerpt (unbraked 31 kph – head deflection 70 cm).

After a wheel makes contact with the head, the head tilts to one side (90°). The time it takes to reach this angle depends on the speed and braking behaviour of the vehicle. When the vehicle is travelling at high speed with high braking deceleration, 90° is reached early. After the wheel is free from the body, the head changes its angle again and returns to zero and also briefly turns into the negative range (depending on the speed, especially at low speeds) and remains in the positive range again (coming to rest). Considering the rotational movement of the longitudinal axis of the body (Figure 7), the head has also reached its maximum angle of rotation when it reaches its 90° position.

Video Sequence of a Head Being Run Over, Top View:

Figure 7: High-speed sequences, total 6 sec. video excerpt (braked 41 kph – head deflection in x = 90 cm).

The extent of this angle is significant and depends on the speed at which the vehicle traverses the head. After reaching this maximum, the thorax begins its deflection movement. The head longitudinal axis angle decreases until both have approximately the same angle. Both the head and thorax now rotate together, with the head always leading slightly.

Thorax as the Crossing Point

If a thorax is driven over (Figure 8), the final position values are significantly higher than for the head. It can be seen that a certain final position is always reached after a front wheel has passed over the thorax if a rear wheel did not also touch the body. As a rule, secondary contact of the body (arms and head are exposed) with the vehicle body also occurs when the thorax is run over.

Video Sequence of a Thorax Being Run Over:

Figure 8: High-speed sequences, total 21 sec. video excerpt (unbraked 48 kph – thorax deflection in x-direction 285 cm).

It is interesting to note that rear wheel contact with the dummy (usually the head) occurred in all thorax runovers. Again, no influence of the speed on the end position values can be determined. Smaller distances in the final position occurred in the unbraked vehicles compared to braked vehicles, as braking partially pushes the body on the road.

The time sequence of the rotational movement of the longitudinal axis of the body shows an almost linear increase to the final value (Figure 9). This increase depends on the crossing point. **The closer the point is to the body's centre of gravity, the greater the maximum angle becomes.**

Thorax as the Crossing Point, Top View:

Figure 9: High-speed sequences, total 13 sec. video excerpt (braked 50 kph – thorax deflection 355 cm).

When a wheel comes into contact with the thorax, the wheel presses into it first, whereby the tyre compresses depending on the tyre air pressure. The maximum compression depth, as far as it was visible in the film, is reached after a certain time (10 to 20 ms). Depending on the crossing point on the thorax, if the tyre crosses far below the ribcage, in the soft tissue of the abdomen, a later onset of body movement can be observed. At maximum compression, the thorax then begins to slide in the rolling direction of the wheel, but without rotating around its longitudinal axis. The rotation of the longitudinal axis of the body starts approximately 10 ms later, with simultaneous movement in the rolling direction. After 100 ms, the centre of the wheel is exactly above the centre of the thorax, which has assumed a rotation angle of 60°. After 150 ms, the wheel begins to come away from the body and the head and right arm begin to lift. The body continues to rotate, whereby the maximum end angle depends on the speed of the vehicle. The bottom of the vehicle is often touched by head or arm impacts. In all tests, no traces of the runover process could be recognised on the axle structure, although there were traces in the sill area underneath the vehicle. In the film analysis, a simultaneous oscillation of the wheel suspension can be seen. The arm, which was caught by the rear wheel and rolled over in some tests, also appears to have a significant influence on the resulting motion sequence; the thorax came to rest in the supine position rather than the prone position. In other cases, the prone position was frequently present.

Conclusions from the Characteristics of the Run Over Process

The final position of a pedestrian who has been run over can be used to determine the crossing point (Figure 10).

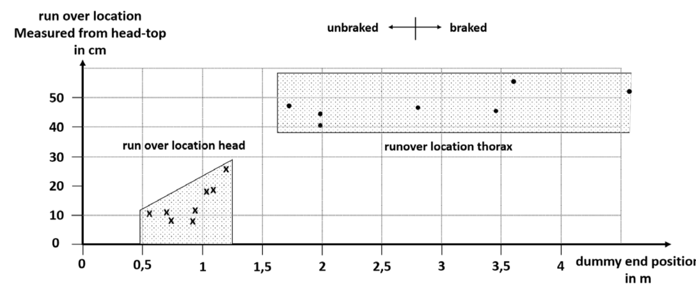

Figure 10: Dummy end position depending on the crossing point.

End position values when a person's head is run over are far below those when the thorax is run over:
For end positions up to 1.5 m, it must be concluded with the greatest possible certainty that the head has been run over.
For end positions greater than 1.5 m, it must be concluded with the greatest possible certainty that the thorax has been run over.
When the thorax is the crossing point, the end positions of the braked vehicle are greater than those of the unbraked vehicle.
There is no dependence on speed (subject to the driving speeds of 30 to 50 kph selected here in the test).

Mechanics of the Runover Process

With the knowledge of the movement sequence of runover, a mechanical replacement model of the overrun body can be created in the form of a 3-rod model (Figure 11).

On a human subject (80 kp), it has been determined with the aid of a foot scale that the body parts
Head 5 kp
Shoulder 24 kp
Buttocks 37 kp
Leg 7 kp each

press on a surface, i.e. on the road.
This results in the following contact surface area

Head	100 cm²
Shoulder	800 cm²
Buttocks	400 cm²
Leg	300 cm² each

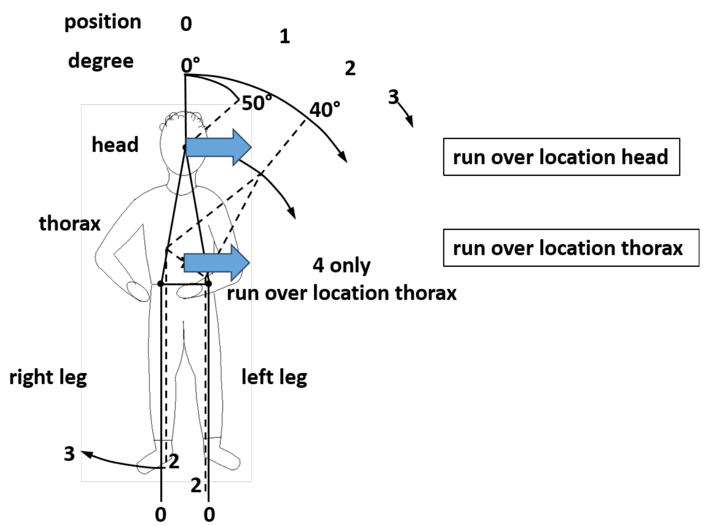

Figure 11: Mechanical replacement model of the pedestrian as a 3-rod model.

This results in a contact pressure of the corresponding body part, with the buttocks exerting the greatest pressure. It will therefore also serve as the centre of rotation for the movement of the upper body, which rotates sideways with its entire upper body longitudinal axis. When the lower extremities are driven over, it can be concluded on the basis of the findings that these are also deflected in the drive-over direction, whereby the body rotates against the rotation of the driven over head or thorax in the direction of the runover, and a positive final position value of the entire body is achieved. The shape of the final position will be similar to that when the head is run over, as the heavier trunk of the upper body forms the friction surface on the roadway.

The movement impulse that is introduced into the body originates in the phase of initial contact between the wheel and the body. The wheel is briefly stationary and the rolling function of the wheel is briefly blocked by the body in an unbraked vehicle. The wheel then rises relatively ‘abruptly’ to the height of the body or deflects and continues to move over the body in the direction of travel.

The mechanics of the motion sequence of a runover can be divided into the following individual mechanical problems:
A rolling wheel hits an obstacle, which corresponds to an impact process with sudden fixation (Figure 12).

This results in an impact force F_{Res}, which acts on the body in a horizontal (F_X) and vertical (F_Y) direction. The latter, together with the weight force of the body G_K and the vertical component of the wheel circumferential force F_U, forms the frictional force between the body and the ground $F_{wheel/tyre}$. It thus prevents the body from sliding further for the duration of the impact (Figure 13).

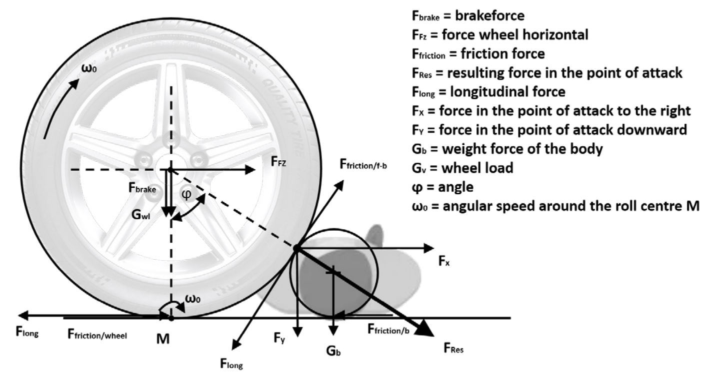

Figure 12: Mechanics of a human body being run over - first phase: contact.

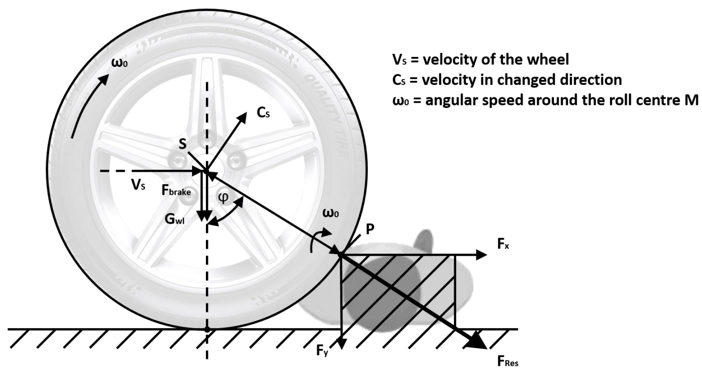

Figure 13: Mechanics of a human body being run over - second phase: fixation.

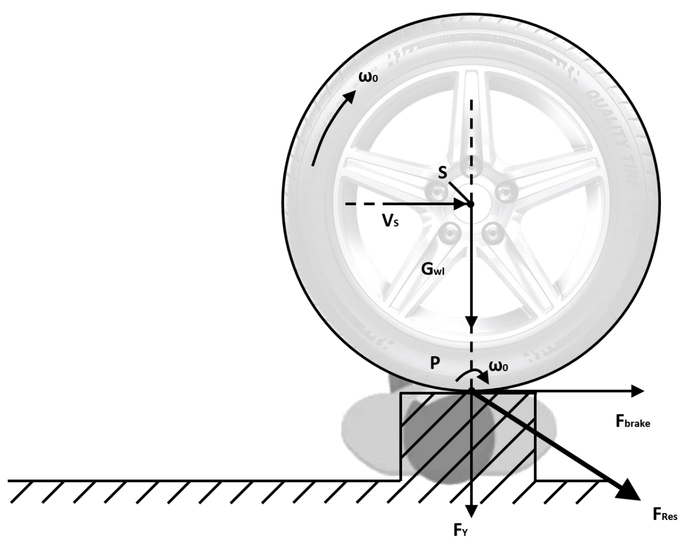

Figure 14: Mechanics of a human body being run over - third phase: lifting and deflection.

There is an abrupt shift of the instantaneous centre from M to P. As the experiments showed, the friction during the impact process in P is so great that no sliding occurs there. However, the impact force F_{Res} acts on the body in P. This also explains the visually sharp tyre marks on the side of the dummy's face at the head impact point. This force certainly also induces injuries. The sudden fixation of the wheel leads to a sudden lifting of the vehicle with deflection of the wheel when the head is also fixed (Figure 14). Here, in addition to the wheel load component $G_{F,\text{wheel load}}$, the horizontally acting braking force F_{Brake} may also act on the head in the event of braking.

The rotational movement or deflection of the body then begins according to the principle of eccentric impact against a rotatably mounted body. When the head is the crossing point, the head is deflected more easily relative to the body trunk due to the relatively easy movement via the neck segments, so that the trunk is moved only slightly from its original position.

In contrast, when the thorax is the crossing point, the force of the impacting wheel is applied directly to the lateral thorax wall, which is pressed in and completely rolled over. With impact near the body's centre of gravity, the entire body is moved in the direction of vehicle motion and a significantly greater distance to the end position results compared to when a head is the crossing point.

Dummy Damage and Expected Injuries

Tyre marks on the side of a dummy facing the wheel are characteristic; these appeared especially on the head but also on the clothing on the thorax (Figure 15), in particular over almost the entire traversed area across the front of the thorax. Also characteristic marks can be found on the body as tissue injuries, i.e. on the arm (Figure 16).

Figure 15: Tyre imprints on the dummy's clothing in the thorax area.

The back of the dummy's head often showed deep scratches caused by the rough tarmac surface when it was driven over. In reality, this corresponds to massive abrasions. Multiple folds in the clothing were recognisable on the back, but otherwise there was no major damage. There were also some small scuff marks on the shoe at the heel due to sliding on the roadway.

Figure 16: Avulsion tissue injury at the right arm; run over location thorax.

In reality, massive craniofacial fractures are likely to occur when the head is the crossing point, while the body as a whole will show relatively few serious injuries. When the thorax is the crossing point, the body shows a greater degree of damage. The upper extremities regularly showed extensive and deep abrasions on the hands. The clothing was also often completely torn.

This means that the thoracic trauma is certainly a serious injury that will result in multiple soft tissue injuries, rib fractures and internal organ injuries in particular. The head can also have many accompanying injuries.

Discussion and Conclusions

Despite the small number of tests carried out from the point of view of a reliable statistical statement, the main objective of the study to determine the mechanics and kinematics of running over a pedestrian lying on the road can be addressed, as the tests showed clear characteristics.

When a vehicle wheel passes over a body, it imparts a movement impulse to the body that causes it to rotate the longitudinal axis of the body around the centre of the friction surface, namely the buttocks, due to the greatest contact force of the body. The wheel moves the body out of its position more easily if it makes contact with it as far away from the buttocks as possible. Friction plays a major role, because the body being driven over would perform a purely translational movement if the frictional force resisting the movement between the body and the road to the left and right of the point where it is driven over is the same. This means that different regions of the body (shoulders, head and legs) are deflected differently. This study refutes the statement by Hörz [11] that one can assume a rod model; when considering rod masses, the body being driven over is at best an approximation of a 3-rod model. Moreover, the pedestrian's body is not to be understood as a circular cylinder, as Kassei [9] assumed, but must be regarded as a rectangular compressible body with varying stiffness. The head is rather hard and the thorax is softer or compressible.

The most important influencing factor in a runover is the point at which the vehicle runs over the body. After analysing forensic literature, it was possible to identify the head and thorax as frequently run over areas of the body and to find characteristics for these by running over a dummy. This study showed that the maximum movement of the body in the rolling direction of the wheel was significantly greater when the thorax is run over (Figure 17) than when the head was run over (Figure 18), and greater for the latter with a braked wheel than with an unbraked wheel. In detail, the temporal distances of the body movements for tests 3, 4, 13 and 15 with an unbraked vehicle show shorter distances compared to tests 7, 8, 16 and 17 with a braked vehicle. In Figure 18, tests 10, 11 and 18 were carried out with an unbraked vehicle and tests 5, 6 and 14 with a braked vehicle.

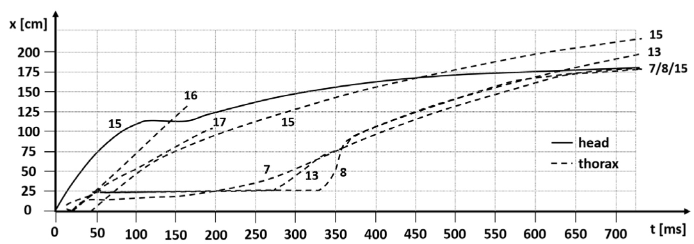

Figure 17: Movement of the body in the x-direction as a function of time when the thorax is the crossing point.

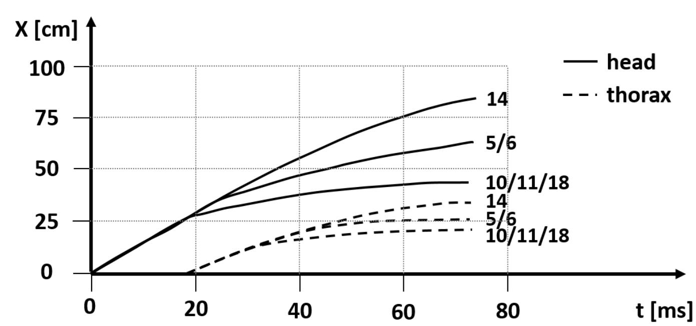

Figure 18: Movement of the body in the x-direction as a function of time when the head is the crossing point.

Due to the large number of influencing parameters and the low speed range achieved in the tests, it is not possible to prove the influence of the crossing speed. However, this can be assumed, so that the distance between the crossing point and the pedestrian's final position increases as the vehicle's crossing speed increases.

The influence of wheel diameter can be taken into account with a corrected runover speed. This is obtained from the different rolling circumferences of the tyres. For example, at the same vehicle speed of the Renault R4 and VW T1 Bus vehicles used here, the wheel speed of the VW is around 15% lower than that of the Renault.

The main characteristic of the runover injury is the double-sided and symmetrical arrangement of the load on the body and the specific track characteristics. The side of the body facing the wheel with the direct point of contact with the tyre surface often bears the tyre imprint and the surface of the body below the wheel load that is in contact with the road surface almost always shows abrasion marks on the back of the head in the case of head runovers or pressure marks on clothing in the case of thorax runovers. Contrary to the statement by Nussbaumer [13], the most pronounced injuries do not occur when the wheels are locked, but when the thorax is run over. There was no discernible influence of braking behaviour on the damage to the dummy and thus the injuries.

The results obtained here do not apply to lorry runovers. A significantly greater weight and resulting higher axle load, as well as larger tyres, produce different results in the distance-time behaviour, but it can be assumed that the behaviour of the victim and vehicle movement is analogous in terms of kinematics. Tests should confirm this.

The tests with dummies must be assessed to a limited extent with regard to the expected injuries. A human body has different characteristics in terms of the strength and structure of skin and bones, so that conclusions can be drawn only in connection with the medical literature. Extensive injuries are often concealed and severity is primarily underestimated. In a study carried out between 1996 and 2005 at the University of Ulm in the Centre for Surgery, Riepl et al. [15] used data on runover injuries collected from patient files to show that, at 68%, massive soft tissue injuries in particular often led to considerable long-term consequences due to decollement. However, the tests carried out here showed that extensive dragging of the body of runover victims, as Stadler et al. [16] stated, is not the rule and is not actually frequent. In contrast to Nussbaumer's statements, Riepl noted the legs as a particularly frequent point that is run over, resulting in so-called avulsion injuries due to shearing mechanisms on skin tissue layers. This cannot be detected by tests with dummies.

Pedestrians being run over by cars are rare events. Isolated medical publications often provide more evidence, especially when only fatalities are considered. For example, in his 2020 dissertation [17], Schick analysed 126 fatal pedestrian accidents and found that 12.5% of them involved people already lying on the road. In GIDAS [3], a representative sample of all accidents with personal injury, the percentage was only 0.15%.

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