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Assessing the safety characteristics of the Segway

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Preface

German lawmakers intend to permit the licensing of vehicles such as the self-balancing electric scooter made by Segway/electric scooter for purposes of public traffic in Germany in the near future. Against this background the Insurers Accident Research took up the subject and assessed the safety characteristics of this vehicle.

Content

1 Introduction

The Segway is a completely novel vehicle concept. In 2001 it was presented to the public by the company with the same name, Segway, for the first time. The company was founded in the USA in 1999 and in the meantime commands an international sales network in 55 countries [1].

According to the manufacturer about 30,000 to 35,000 vehicles have been sold since the start of production; of this figure about 1,000 have been sold in Germany. To date this novel vehicle concept has not succeeded in achieving the big breakthrough.

As far as the German market is concerned, this is not least the result of its sales price of about 7,000 Euro. This situation could however change: given dropping sales prices and the current discussion on CO2-emissions in road traffic and climate change, the Segway offers an interesting opportunity of emission-free transportation in urban areas.

Picture 1:
The Segway - a vehicle concept with a future?
Source: Segway

2 Mode of operation

The Segway is an electrically propelled two-track vehicle with only one axle, which is self-balancing. It is driven whilst standing in the upright position. Acceleration and braking are effected by weight-transfer. For taking curves the handle bar must be moved left or right. As such the driver is electronically and fully automatically stabilised in his/her position at the centre of gravity by the vehicle. This is done with the aid of five gyroscopic- and two acceleration sensors. These transmit data on the vehicle- and body positions at a rate of 100 times per second and correlate them.

The centrally processed information is superimposed on the driver's intention. The central calculator of the vehicle then passes on the steering commands to the two electrical engines. Table 1 shows the technical data of the Segway PTi2.

The Segway PT already represents the second generation of the model. The first model was called Human Transporter (HT) and was sold as the i-series and p-series. The current model series PT is being offered as the i2-series and x2-series.

The generational change in the model has also brought about a change in the way the vehicle operates. Driving to the left or to the right is now effected by pushing the handle bar in the direction respectively desired. In the first generation model series this was effected through turning the grip on that side of the handle bar in which direction one intended going.

Top speed	20 km/h
Maximum payload	118 kg
Base	63 x 63 cm
Kerb weight	47,7 kg
Batteries	2 Saphion® Litium-ionic-batteries
Range	up to 38 km, depending on surface and driving style
Motors	2 brushless DC servo-motors
Wheels	Ø 35 cm, fiberglass-reinforced thermo-plastic
Tyres	Ø 48 cm, puncture-resistand tyres
Platform height	21 cm
Ground clearance	7,6 cm
Display	cable-less info-key steering device

Table 1:
Technical specifications of the Segway PT i2 (Personal Transporter)
Source: according to Segway

3 Use in public traffic

With the introduction of the Segway in Europe considerations regarding the applicable European legal framework governing its use in public traffic were initially undertaken. The EU Commission however determined that in this regard no European regulation comes into consideration as the vehicle merely permits trips or rides covering short distances, and that, therefore, its regulation falls in the legal ambit of local and national authorities [2].

3.1 Licence classification

On the whole the licensing of new types of vehicles puts traffic law in a quandary again and again. Whether and on which road surfaces a vehicle can be driven in public traffic is determined by the legal framework covering vehicle licensing. Accordingly a number of possibilities of licensing the Segway merit consideration [3], [4], [5]. However, in licensing and classifying the Segway it always has to meet the specific and technical requirements of the individual vehicle type. Imaginable is:

- its classification as a car;
- its classification as a scooter, a wheelchair, a motor-assisted bicycle or a light moped;
- its classification as a special mode of transport;
- a technical restriction of the top speed through construction requirements to a maximum of 6 km/h; and
- its classification as a vehicle in its own right (electronic mobility aid).

Its classification, for example, as a light moped could only be considered if the regulation governing the weight of mopeds is changed, because the Segway would otherwise be too heavy. Its classification as a special mode of transport would, on the other hand, respectively require ministerial approval or a change in the German Traffic Regulations Ordinance (Article (§)16 of the Ordinance). The technical restriction for reasons of design of the top speed to a maximum of 6 km/h, would, on its part, lead to the falling away of the driving licence-, crash helmet- and obligatory insurance coverage requirements. The vehicle, however, would then be restricted in its use to areas reserved for pedestrian traffic.

3.2 Legal situation

Against this background the German Federal Ministry of Transport (BMVBS) has recently submitted a draft Mobility Assistance Ordinance (MAO/Mob-HV-E) in order to create a uniform legal basis at national level for the Segway's participation in traffic. It provides for the eventual classification of the Segway as a "vehicle in its own right".

The legal instrument of using a special ordinance which grants exceptional authority for licensing is indispensable. Even the best of ordinances cannot possibly anticipate numerous single cases and regulate them. Having the option of exceptional authorisation hence is vital for the flexibility of traffic/transportation law, e.g. to promote new technologies or prevent unnecessary harshness or rigidity. The legal basis for the Mobility Assistance Ordinance is provided by Article (§) 47, para. 1, nr. 3 of the Vehicle Licencing Ordinance (VLO/FZV), which grants the Federal Ministry of Transport the power to decide exceptional arrangements without the approval of the Bundesrat and after a proper hearing by the competent authorities at federal state level.

With the coming into effect of the new ordinance the existing and differing regulations at federal state level can then be harmonised. To date Bavaria, Berlin, Hamburg, North Rhine-Westphalia, the Rhineland Palatinate, the Saarland and Schleswig-Holstein provide for such exceptional authorisations [6]. These are coupled to certain provisions and requirements, and can differ from federal state to federal state.

The background to the aforementioned is that according to Art. (§) 47, para. 1, nr. 1 of the Vehicle Licencing Ordinance (FZV) the competent highest authorities at federal state level are permitted to deviate from the regulations of the FZV and are permitted to authorise exceptions in certain individual cases or in general for specific applicants.

3.3 Insurance coverage

The framework for the evaluation of vehicle insurance related questions is provided by the Obligatory Insurance Law (PflVG) as well as, in future, Article 2, para. 1, nr. 2 of the Mobility Assistance Ordinance (Mob-HV-E). According to Art. 1 of the PflVG the owner of a motor vehicle with a fixed place of residence in the country is by law obliged to possess third-party liability insurance and to maintain such insurance when the vehicle is used on public roads or places. According to Art. 2. para. 1, nr. 2 of the MAO/Mob-HV-E using the Segway on public roads would only be permissible when it displays the required insurance indicator.

A number of motor vehicle insurers in Germany in the meantime offer insurance coverage for the Segway. Mentionable in this regard are third-party liability insurance, comprehensive insurance (against dangers such as theft) and business liability insurance (e.g. at fairs, events, demonstrations). Current market developments show that Segways are increasingly being used as so-called self-driven rental vehicles. Self-driven rental vehicles are motor vehicles rented primarily at specialised car rental agencies and then driven for own business purposes by the hirer him- or herself or by a person acting on his or her behalf. Examples in this regard are guided city tours and renting such vehicles for fairs. Compared to a normal owner or driver of a Segway, the latter user-group poses a higher risk from an insurance coverage perspective.

3.4 Other legal aspects

The Road Traffic Act (StVG) prescribes that persons wishing to conduct a vehicle in the public domain require a driving licence (Art. 2 of the StVG). The lawmakers' considerations in this regard are that the driver is taught and learns considerate and legal road behaviour during his/her moped-/driver-training so that, in setting the minimum requirement of proof of the right to bear a licence to conduct a moped, the interests of road safety are met and harmonised with the mobility needs of the users of electronic mobility aids. Hence according to Art. 3 of the Mobility Assistance Ordinance (Mob-HV-E) the minimum requirement will in future be proof of authorisation to ride a moped.

4 Evaluation of the safety characteristics

The evaluation of the road safety characteristics entailed the analysis of the operating characteristics of the Segway, the driving characteristics including a driving test on a test track as well as two crash tests. In the case of the latter the collision of a Segway with a stationary pedestrian enacted the exposure to danger and likely injury of such a pedestrian in a potential collision. In the case of the second line-up the collision of a Segway against a stationary vehicle was tested to establish the risks for the Segway-drivert.

The driving tests were conducted on the DEKRA test terrain in Klettwitz, whilst the two crash tests were performed at the DEKRA test facility in Neumünster.

In the whole of Germany there is only one other scientific study on the Segway. The latter relates to the scientific monitoring of a Saarland pilot project by the Technical University of Kaiserslautern as commissioned by the Federal Highway Research Institute (BASt) [7]. The evaluation of the safety characteristics of the Segway by means of conducting two crash tests remains unique in the international context. In assessing the safety characteristics, one of the basic rules pursued was viewing the Segway in its relativity to other vehicles of a comparative nature, e.g. the bicycle.

4.1 Operating features

In general it can be said that learning to ride the Segway is quite easy and that its integration into normal public traffic can occur if the points here described, are heeded. With longer use progress in the proficiency of handling the vehicle is quickly achieved.

The investigations showed that mounting and dismounting or getting on and off the Segway created problems initially for test persons, but after practise were well under control. The vehicle can only be laid down or leaned against another object. A stand similar to the one for bicycles provides some assistance, however, it is only offered as an option. Acceleration and steering the Segway are learnt very quickly. Braking is problematical especially in critical traffic situations that arise unexpectedly. In this case focused, intensive practise is required. Indicating a change in the driving direction is a challenge for inexperienced riders, but is effected effortlessly with greater proficiency. Reversing with the Segway can be learnt, but it can practically be prevented with easy stationary turning. The light system should be similar to that of a bicycle. A bell should also be mounted to act as acoustic warning signal.

4.2 Driving characteristics / test track

In order to investigate the driving characteristics of the Segway only competent riders with more than three hours of riding experience were made use of. The Segway manages inclines of up to 20% on both tarred and gravel surfaces effortlessly. Lowered kerbstones are manoeuvrable (see Picture 2). Kerbstones with a height of 110mm are however not manoeuvrable.

Driving with under-inflated tyres is unproblematical. Braking with low fiction coefficients (μ = 0.4, μ = 0.12, μsplit = 0.8/0.12) is also uncomplicated. Driving on wet surfaces creates no problems (see Picture 3).

Picture 3:
Circular ride on a wet track/surface

The braking distance in the case of emergency braking at 20 km/h was markedly longer for most test persons than with a bicycle with back-pedalling. Using a bicycle a braking distance of between 2.7m and 4.1m was achieved. With the Segway the best test rider achieved a braking distance of between 2.2 and 2.9m. All other test riders achieved braking distances of 4.7 to 5.7m (see Picture 4). The decelleration was between 3 and 5 m/s².

Generally it can be said that swerving and braking make up the two most important handling

Picture 2:
Unproblematical manoeuvring of a lowered kerbstone

Picture 4:
Comparison of braking distances Segway and bicycle

modes, which should be practiced intensively in order to ride safely at the level of a bicycle.

A third step was for inexperienced riders to complete a 300m test track that recreated situations often encountered in normal traffic (see Picture 5).

In the process inexperienced riders are enabled to learn driving tasks quickly. Critical situations that arise unexpectedly or emergency braking overburden inexperienced test riders. In contrast experienced test riders achieved positive results in this exercise. Initial quick learning successes can lead to an overestimation of own abilities in riding the Segway. It can be concluded that a comprehensive special driving course is essential in order to drive the Segway safely in traffic.

Picture 5:
Driven sections of the test track
(top: braking, bottom: obscured sight)

4.3 Crash tests

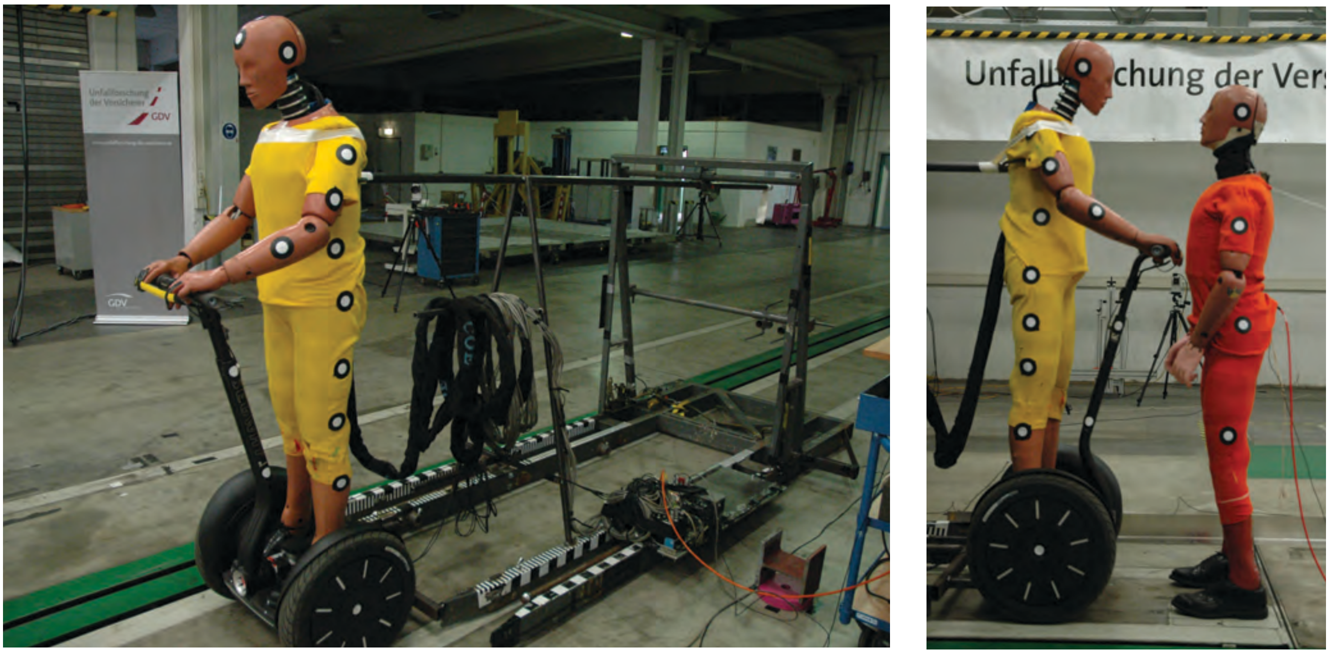
The conducted crash tests had the purpose of putting the Insurers Accident research in the position to assess two aspects, namely, the danger emanating from a Segway for a pedestrian on the one hand, and the risk involved for a Segway-rider in a collision with a motorised two-track vehicle on the other hand. In conducting the crash tests measuring instruments and test systems that had proved themselves in ordinary vehicle crash tests were used. In both tests the Segway was crashed in an inoperable mode.

Pre-tests had shown that under the chosen requirements the influence of the electronic steering on the test sequence was negligible. However, future tests under other conditions (e.g. the impact angle, collision opponent) should investigate anew the possibility of testing under fully operable conditions. It cannot be excluded that the electronic steering can lead to deviations in the known kinematic sequence during tests with the Segway.

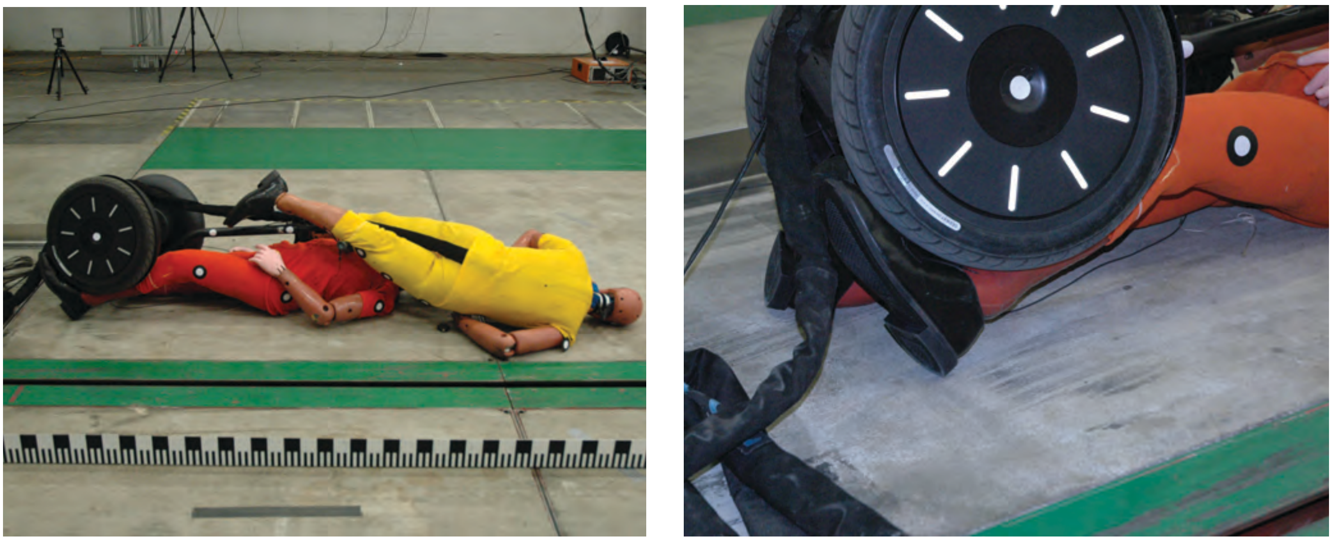
4.3.1 Segway crash test against a pedestrian

In conducting this test a stationary pedestrian is represented by a MATD-dummy (MATD – Motorcyclist Anthropometric Test Device). This dummy was developed especially for motorcycle crash tests. The basic composition of the MATD-dummy is very similar to that of the Hybrid III-dummy. There are big differences in the area of the neck, chest and lower limbs:

In comparison to the Hybrid III-dummy the neck does not show a preferred direction and is fitted with an additional joint. The chest can measure variable impact directions. The legs have movable knee-joints and breakable lower legs. For this very reason the MATD-dummy was selected to represent a pedestrian. The Segway-rider is represented by a Hybrid III-50%-dummy. The Segway approaches the pedestrian with a speed of about 15 km/h. For this purpose it is catapulted by a test sled in order to roll freely before colliding with the pedestrian held in position by a rope (Picture 6). The test sequence is shown in Picture 8. The resulting final positions of the dummies and the Segway are shown in Picture 7.



Picture 6:
Test configuration
(right: test position, left: test sied)

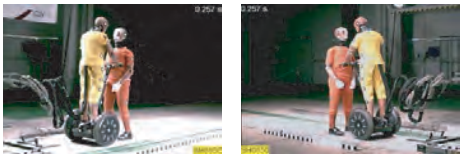


Picture 7:
Final positions

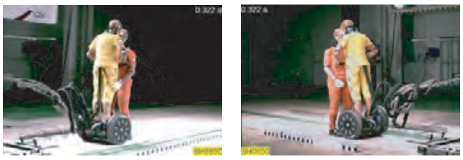
Time [ms]

0 Starting velocity 15,3 km/h
t = 0 with decelerating test sled

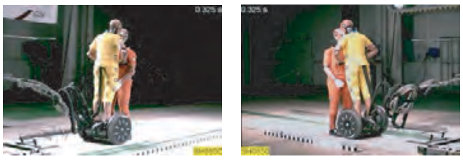
257 First contact rider/pedestrian



322 Head impact
Pedestrian
Head deceleration
a 3 ms = 20,15 g



325 Max. Segway deceleration
az = 13.56 g

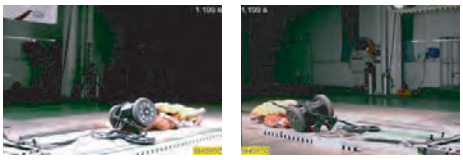


813 Crash pedestian/ground
Pedestrian
Max. head deceleration
a 3ms = 200,74 g
HIC = 14217

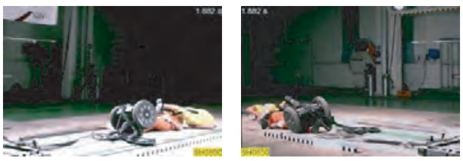
825 Pedestrian
Max. pelvic deceleration
a 3ms = 47,34 g

1156 Impact pedestrian/Segway-rider
Pedestrian
head deceleration
a 3 ms = 23,78 g

1199 Crash Segway-rider/ground
Segway-rider
Max. head deceleration
a 3 mx = 40,21 g
HIC = 1993



1882 End of impact



Picture 8:
Test sequence

Four critical situations can be observed during the collision:

- The mutual head-on collision leads to high accelerations in both dummies and hence to serious head injuries.
- The crash of the Segway into the pedestrian's legs leads to a severe impact on the lower legs and ankles with resulting serious leg injuries.
- With the impact of the pedestrian's head on the ground, very high measurement values are generated in the areas of the head, neck, chest and pelvis. The interpretation of these results is problematical, because the limits of the dummy model (see Picture 8; t = 813 ms) are exceeded by the impact directions. In all likelihood intensive injuries occur in the abovementioned areas.
- During the impact of the rider's head on the ground high neck- and chest forces as well as a very high head impact are measured. These lead to severe injuries. Especially in the head area this can lead to irreversible or fatal head injuries.

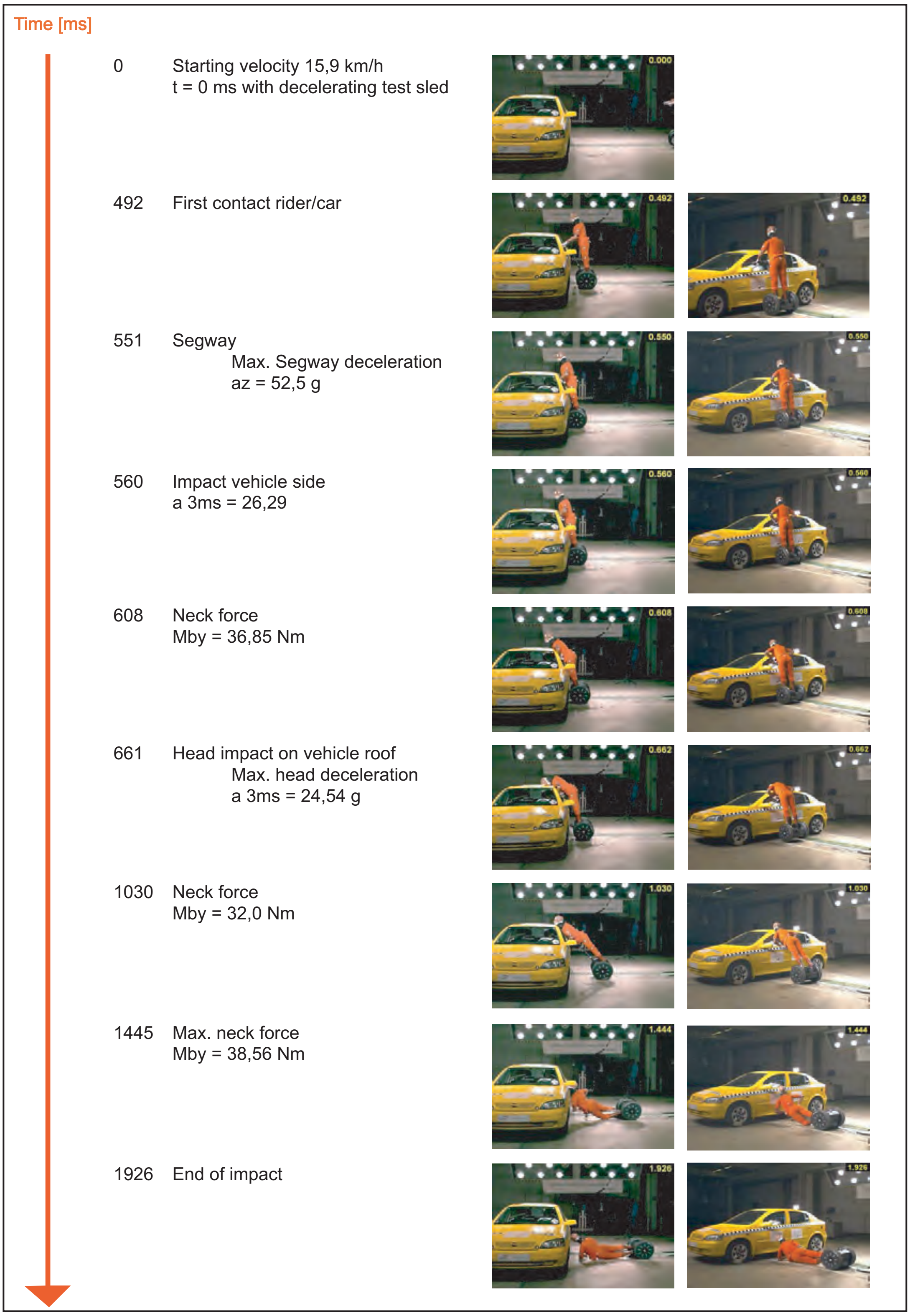
The test configuration represents the approximate conditions during a real pedestrian-Segway collision. Naturally the reactions and reflex actions of the persons involved (bracing the impact, clutching/embracing) which can lead to more positive kinematics and hence to lower measurement values with a smaller probability of serious injury cannot be excluded. However, it should be mentioned that a collision between a pedestrian and a bicycle or an inline-skater travelling at the same speed can lead to similar results.

4.3.2 Segway crash test against a vehicle

In this configuration the Segway crashes into the side of a stationary vehicle at a speed of approx. 15 km/h. The Segway-rider is represented by a MATD-dummy. The stationary car is a 1998 Opel Astra. The test configuration is shown in Picture 11. The Segway is again catapulted by a test sled, then rolls freely and collides at a right angle to the vehicle's longitudinal axis with the stationary vehicle. The vehicle is occupied by an un-inshumanted Euro-SID dummy in the driver's seat (see Picture 10).

Picture 9:
Crash test configuration

Picture 10:
Euro-SID dummy in the drivers seat



Picture 11:
Test sequence

The given differences in size between the vehicle and the Segway are crucial for the sequence of the collision. These differ clearly from those vehicles known to date like a bicycle or a motor cycle. The Segway-rider clearly stands out above the vehicle so that there is no direct head contact with the roof-edge, as normally occurs in comparable collisions involving two-wheelers (see Picture 9).This particular impact configuration is characterised especially by high forces in the neck area of the Segway-rider. These occur at three different points in time and can be taken as typical for this kind of test configuration. Thereby the forces on the neck don't exceed the legally prescribed limits taken from the ECE-R 94/95 tests, but would nonetheless lead to serious or severe injuries.

Summary

The crash tests demonstrate that the Segway – at least at the tested speed of 15 km/h – holds danger for pedestrians. At the least this can be linked to the large total mass. But at these speeds Segway-riders expose themselves to danger that is not to be underestimated, not only in a collision with a pedestrian but also during a collision with a vehicle. The driving tests on the other hand showed that the Segway is uncomplicated in its handling. However there are situations like sudden swerving and breaking that can only be addressed successfully with special extensive training.

The Insurers Accident Research therefore recommends:

- Segways should only be driven in traffic after special training.
- Segways should in the first instance only be ridden on cycle paths. Use on roads is not recommended.
- Segways should be permitted to drive only at a maximum speed of 6 km/h in pedestrian zones and on footpaths, apart from that a speed of 9 km/h is recommended by the Insurers Accident Research. This is based on the speed limit for which Segways being used during guided city tours are governed or limited.
- Technically Segways are to be treated like bicycles (light, bell, stand, time switch).
- Every Segway-rider should in principle wear a crash helmet (cycle helmet).
- Insurance coverage must be guaranteed and can be followed by an insurance indicator.

Additional Information

Media releases:
http://www.unfallforschung-der-versicherer.de/Unfallforschung/PR/pr_meldung_2105_2008_segway.htm

Specialised information and films:
http://www.unfallforschung-der-versicherer.de/Unfallforschung/FS/Aktuell/aktuell_segway.htm

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