PEDESTRIAN DETECTION AND DRIVER ATTENTION
Cues needed to determine risky pedestrian behaviour in traffic

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Author: Annika Larsson
Master thesis in Cognitive Science
Department of Computer and Information Science
Linköping University, Sweden

Supervisor and Examiner: Prof. Erik Hollnagel
Department of Computer and Information Science
Linköping University, Sweden
ABSTRACT
The purpose of this thesis was to determine which perceptual cues drivers use to identify pedestrians that may constitute a risk in traffic. Methods chosen were recordings of pedestrian behaviour in Linköping by means of a stationary video camera as well as video camera mounted in a car. Interviews on the recordings from the mobile camera were conducted with taxi drivers and driving instructors.

Results include that drivers not only react to pedestrians they believe will behave in a dangerous way, but also react to pedestrians that probably not will behave in such a way, but where the possibility still exists. The study concluded that it was not possible to determine how risky a pedestrian is considered to be by only using behavioural factors such as trajectory or position on the sidewalk, and distance. It is necessary also to include environmental factors, mainly where the pedestrian and car are positioned in relation to the side of the road, so that the behaviour of the pedestrian can be interpreted.
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INTRODUCTION

Now, when airbags are commonplace and passive safety almost has reached its limits, it is time to look toward what can be done to prevent collisions in the first place, especially when it comes to pedestrians. Pedestrians can be protected at low speeds by design of the car, but at a higher speed that alone will not reduce the fatality rate of the pedestrians.

Another approach would be to prevent the actual collision, or at least reduce the energy in a collision either by warning the driver or by the car itself initiating the braking.

The objective of this study was to relate the pedestrian behaviour to what behaviour a driver actually feels is “risky”, something that needs to be focused more upon. The study aimed to find the cues used by drivers to determine that a certain pedestrian might behave in a way that could cause them to be hit by the driver. These cues may constitute a starting point for a night-vision system that can warn drivers about pedestrians.

Autoliv Research was the commissioner of the study.
1 LITERATURE REVIEW

An overview of pedestrian safety in urban areas is given, among which a review of the fatality rate for pedestrians being hit at given car speeds. Following that, a sample of different theories related to drivers and perception is presented. These theories include driver-based perceptual zones relating to the car, Brunswik’s lens model, Neisser’s perceptual cycle, recognition primed decision making and change blindness. Lastly, several attempts at pedestrian detection and modelling pedestrian behaviour are looked at whereafter the problem is described.

1.1 Pedestrian safety in urban areas

On average, over 5,000 pedestrians were killed each year in the U.S. 1991-2001 (U.S. Department of Transportation, 2003). In urban areas, most accidents where pedestrians were hit by a car occur either at a non-signalised zebra crossing or at a signalised intersection. Ekman (1988, in Ekman and Hydén 1999) collected data 1979-1984 to see if over-representation was due to the higher exposure at non-signalised zebra crossings or not. Ekman found that crossing on a non-signalised zebra crossing seemed to result in a higher risk for the individual pedestrian to be injured than crossing anywhere else, exposure accounted for. He also found that signalised pedestrian crossings do not provide a safer place to cross either, with the possible exception of for the elderly and children. Ekman explained this by pedestrians feeling a false sense of security when protected by a zebra marking or signalisation, when no help is provided the pedestrians cross with more care. In a latter study, Ekman (1996, in Ekman & Hydén 1999) compared the accident rate at intersections with and without zebra crossings. In this study as well a (significant) higher accident rate was found at zebra crossings.

The U.S. Department of Transportation (2003), conclude that dark and dark but lighted conditions account for almost two-thirds of pedestrian fatalities. There are 4.1 times as many fatalities in darkness (dark and dark but lighted conditions) as in daylight according to a report by the University of Michigan Transportation Research Institute (Sullivan and Flannagan, 2001). According to the Swedish Road Administration (Vägverket 2004), 40% of all accidents where pedestrians are involved occur in dark conditions, even though fewer pedestrians are present then.

Várhelyi (1996, in Ekman & Hydén 1999) has carried out an in-depth study of driver and pedestrian behaviour at a non-signalised zebra crossing, with special emphasis on drivers’ choice of speeds when approaching the crossing. The results showed that of 824 interactive situations the pedestrian crossed before the vehicle in only 5 percent of the cases. In only one situation was the pedestrian mostly allowed by the driver to cross in front of the car; this was when the car was more than 4 seconds away from the non-signalised crossing (about 55.6 m at 50 km/h). In this situation vehicle speeds were lowered since drivers thought that it was no use in trying to pass before the pedestrian. This also made it more probable that the pedestrian actually did pass before the vehicle.

In May of 2000, traffic rules in Sweden were changed, there is now a requirement for drivers to yield for pedestrians at non-signalised zebra crossings. This change is one part of a Swedish project to decrease deaths and serious accidents in traffic. The effect
of the requirement to yield was discussed in a report from VTI (the Swedish National Road and Transport Research Institute) in 2004. The report concluded that a slight but not significant increase in deaths can so far be recognised. There is however a slight increase in serious and mild accidents. (VTI, 2004)

### 1.1.1 Speed

One way of reducing the number of pedestrians killed is reducing the speed of impact.

The graphics below (fig. 1), from the Swedish National Society for Road Safety (NTF), show the difference for pedestrians in being hit by a car going 30 km/h versus 50 km/h. The fatality rate for pedestrians hit at 50 km/h is 40-80%, whereas for 30 km/h only 10% (6-16%). At 60 km/h, the fatality rate is not below 75% in any of the studies. NTF use the mean value of these studies.
Stopping distances from various speeds (fig. 2) below, graphics from the Swedish National Society for Road Safety (NTF). The distances are based on dry tarmac, a retardation of 0.8g, and a fast reaction (1 second), NTF (1998). The Y-axis shows speed in km/h, X-axis shows braking distance in meters. The flat portion corresponds to the 1-second reaction time. This graph not only shows the stopping distances, it also can show the distance to when the car has slowed down sufficiently not to kill as many pedestrians, such as that a car braking from a speed of 50 km/h needs to travel just below 25 m, including the 1 sec reaction time, to retard to 30 km/h. Of these 25 m, 14 m is reaction distance and 11 m is actual braking distance.

1.2 Drivers and perception

This section describes perception and its relation to traffic safety from various viewpoints, such as the concept of the field of safe travel, the lens model, the perceptual cycle, recognition primed decision making and change blindness.

1.2.1 The field of safe travel and the minimum stopping zone

Gibson and Crooks (1938) define the field of safe travel and the minimum stopping zone, two fields completely subjective to the driver, existing in his or her own mind.

According to Gibson and Crooks (1938), all perception is selective, so also the driver’s field of view. The elements pertinent to locomotion stand out, Gibson and Crooks explain, whereas scenery normally recedes into the background. The most important part of that pertinent field is, of course, the road. Within the road also lies the “field of safe travel” (see fig. 3), a field completely subjective to the driver, it is the field of possible paths which the car may take without hindrance. The extent of the field is determined by objects or features that are obstacles. The field is not fixed, but moves with the car through space, its point of reference being the driver. It changes and shifts constantly, contracts and elongates, bends with the road dependent of the environment, i.e. obstacles. Gibson and Crooks also define “the minimum stopping zone”, which is defined by the minimum braking distance required to stop the car. In other words, if the minimum stopping zone was clear from other traffic elements, the driver would always be able to avoid a collision.
Further, concerning obstacles, Gibson and Crooks pose the thought that every obstacle has a sort of “halo of avoidance” around it, represented by lines of clearance much like contour lines on a map, with each line closer to the obstacle representing a greater intensity. In regards to moving obstacle, the clearance lines radiate from where the obstacle will be when the driver’s car comes closest to it – the point of potential collision (fig. 3). The more unpredictable or the greater the speed of a moving obstacle, the more extensive are its clearance lines. The field of safe travel is in such a way determined by the future clearance lines of a moving pedestrian, Gibson and Crooks explain.

There also exists “the field of the other driver” according to Gibson and Crooks. Another driver who has not seen one’s own car obviously has an apparently incorrect field of safe travel, with clearance lines encroaching unduly on one’s own field. These affects one’s own field of safe travel in such a way that the field could become very limited, and force oneself to react. This is also viable to apply to pedestrians – they too have a field of safe travel.

Gibson is otherwise best known for his work regarding “affordances”, the perception of meaning in a situation. By affordances Gibson means all different uses of an object that exist. Gibson further declares that these affordances of an object can be perceived immediately. The unchangeable attributes of a pen affords for example writing, pointing, poking and such. These affordances are however different to different people, since the affordances depend on who perceives the object. The perceiver in turn chooses among these attributes and affordances due to specific readiness for some but not for others. To an old man, a tree might afford shadow, whereas to a child it may afford climbing. Perception of meaning depends, as well as perceiving of other aspects of the surroundings, on the person’s cognitive map of the world that control the collecting of information. (Gibson 1966 in Neisser, 1976)
A pedestrian walking across the road can have the affordance of an obstacle, whereas a pedestrian walking along the road only in some cases is considered an obstacle. The pedestrian affordance of both being an obstacle and not is as described above something which may be perceived differently in different drivers. Some drivers may consider a pedestrian an obstacle whereas others would not.

1.2.2 The Lens Model

According to Brunswik (1955), people vary in their perceptions of the same environment according to their previous experiences and other factors such as what they have heard. Brunswik explains that there is, for example, real danger and perceived danger. The perceived danger does not have to be the same as the real danger since our perceptions of dangerous environments, for example a dark footpath, does not necessarily contain anything dangerous but if we have read about dangerous things occurring there, we can consider it to be more dangerous than it really is. Brunswik’s model is based on the assumption that complex stimulus patterns are being processed as through a conceptual lens; the stimuli, which exist all over the place, are focused into a single perception of the environment. The way in which the processing takes place is according to the model dependent on the cue utilisation; a person’s weighting of cues with, for example, perceived danger. I.e. how important one cue is thought to be in determining the perceived danger in a situation. The model assumes that we do not use all cues in the environment, only the most important ones, and re-shape them according to our own experiences.

A further explanation of the model is that we unconsciously, or even consciously, select distal cues (i.e. objects of the environment or outside world). The observer’s subjective impressions of the distal cues, however, are called proximal cues, the next step in the model. In such a way, the fact that the traffic light is green (distal cue) may signalise “safe to go” (proximal cue) to a driver. A proximal cue also has the possibility of being influenced by several distal cues (fig. 4). According to the model, cue utilisation is the probabilistic weights given to each proximal cue by the observer.
The ecological validity in turn is the probabilistic accuracy between the environment and the distal cue (ibid).

The cues, both proximal and distal, in themselves have a probabilistic (uncertain) relation to the actual occurrences. Brunswik’s theory states that sensory information never accurately reflects the real world but is rather ambiguous by nature. No single cue is a perfect predictor of the real world; each cue has a certain probability of being an accurate cue to the environment.

The lens model is evaluated through determining “achievement”; the match between the real environment and the perceived environment. If cue utilisation closely matches the ecological validity, achievement will be high. Through experience, people learn which stimuli are the most accurate reflections of the real environment, and these are consequently given more weight in the organisation of future perceptions, according to Brunswik’s model.

1.2.3 The perceptual cycle

The perceptual cycle (fig. 5), from Neisser (1976) shows the mutual relationship of schema (i.e., knowledge about the environment) directing the exploration of the environment (i.e., actions), which samples the information available for pick up in the environment, which then modifies the schema, and so on. The cycle is used to provide
a description of how knowledge, perception, action, and the environment all interact in order to achieve goals.

There is a difference between this model and other, linear, information processing models. This difference lies in that the linear models presume that an image, for instance, is firstly detected. Then the information from the eye is controlled and combined with information stored earlier by a series of processes, which eventually give rise to a perceptual experience. However, these linear information processing models lack such things as meaning, context and perceptual development; that two people can notice different things about the same actual world. (Neisser, 1976) The perceptual cycle instead takes focus on the cognitive structures that prepare the person perceiving to receive certain kinds of information rather than others and thus control the activity of seeing.

Schema is the term for the cognitive map of the world that directs the perceptual exploration of it. The schema contains the anticipations about how the world should act. It is the part of the perceptual cycle which exists within the perceiving organism and in some way is specific to what is being perceived. The schema is based on earlier experience about the given situation, person or thing, and can be altered through other, new, experiences. The schema supports the observer in perceiving the world through directing, for example, what to see. When approaching a road crossing while driving, one would for example expect to see other cars, and if the road is large, several cars due to having learnt that a large road implies more cars. That does not however imply that one can only see what is expected. A first, unusual, aspect of the appearance of an object would alter the schema, that altered schema would then direct the continued exploration of the object. Through that the schema selects certain types of information ahead of others; schemas do not create faulty perception or illusions. Instead, the mutual relationship between schema and situation implies that neither alone determines the course of perception. Through the schema, perception is selective. An inexperienced driver may see a hedge with a flag above it and see it as a hedge, whereas a more experienced driver may see that same hedge and also notice the little red flag above it, but see that the flag is travelling toward the road, indicating there is a child on a bicycle behind the hedge.

Neisser also states that perception is an active process directed by awareness so that some objects rather than others are selected to be perceived in a more detailed way. Neisser emphasises that the cognitive cycle is just that, a cycle, which cannot be cut into individual pieces without the general idea of it being lost. (Neisser, 1976)

1.2.4 Recognition Primed Decision Making

There is a difference between a novice driver and drivers who have been driving for a longer period of time, of course. The more experienced drivers, verging on or being experts, have the ability to make qualified and better decisions as describe by the Recognition Primed Decision Model (RPD) in Klein (1999). The RPD is a model for decision making in naturalistic settings under time pressure. The model is an alternative to the traditional way of thinking that one weighs different alternatives against each other to reach a decision. The RPD model instead builds on the recognition of cues in the situation which can be linked to the person’s knowledge and experience of earlier occurrences. Experience then enables the person to recognise a plausible course of action instead of methodically contrast it with alternatives. Skilled decision makers usually also generate a good course of action on the first try.
The RPD consists of four steps, a prototype match, forming of expectations, evaluation and last implementation. First, the situation is matched to a prototype based on the perceptual cues, goals and knowledge of causal factors. That prototype then generates expectancies for the situation and a set of options with the most typical option first. The course of action is then evaluated for how well it will work – the RPD does not generate the best solution but rather a workable solution. If the course of action has a reasonable chance to succeed, it is implemented. If it does not, it is adapted to better suit the situation. The last two steps however occur at almost the same time, and the whole process is very fast. Nonetheless, also less experienced drivers can make decisions as in the RPD model; the difference lies in the less experienced drivers naturally have less experience to draw on. As a result the less experienced driver may generate a poor prototype match, resulting in a bad decision. The RPD model was developed utilising decisions made under extreme time pressure, where the decisions would affect lives and property, much as they would while driving a car. (Klein, 1999)

1.2.5 Change blindness

Change blindness is the term for failing to see an object due to not having attended to it. The change blindness theory has been developed by among others Donald Rensink (Rensink, O’Regan and Clark 1997), who found that attention is necessary to detect changes in scenes. The paper supports the notion that observers never form a complete, detailed, internal representation of their surroundings, but rather actually see only what they attend to. Observers do not have an internal representation of a scene which allows them to perceive change automatically. Therefore, if there is no focused attention directed at the part being changed, the contents of the visual memory is simply replaced by the next stimuli. Rensink et al present the example of a driver whose mind wanders during driving. That driver can often miss important road signs, even if the signs are decidedly visible. The information needed for perception is there, in the world, for the driver. What prevents the observer from using this information is the lack of attention directed at that specific element. Therefore the detection of change in a scene occurs only if attention is given to the part being changed. (Rensink, 1997)

In a later article, Rensink (2001, in Jenkin and Harris, 2001) argues that the perception of a scene does not involve a steady build-up of detailed representation; it is rather a dynamic process with focused attention playing one of the main roles to form coherent object representations whenever needed.

The studies by Rensink et al were made on 2-D displays, whereas Simons and Levin (1998) made a study on change blindness in the real world, whereafter they rejected the possibility that change blindness was a result of passive viewing of 2-D displays. In one experiment, when the experimenter had initiated a conversation with a pedestrian, the experimenter was secretly replaced by a different experimenter. If the experimenter dressed as though he was from a different social group, such as a construction worker the experimenter, the change went undetected; the pedestrian categorised the experimenter as a construction worker and did not retain the individuating features of the experimenter. When there was no difference in social group, i.e. the experimenter was dressed as a normal person on campus the pedestrians detected the change in half the cases. Hence Simons & Levin conclude
that if the meaning in the scene is unchanged, a change can go undetected even during natural real-world interaction.

1.2.6 Connecting the perceptual theories

The field of safe travel is a perceptual and subjective field which lies within the road. The driver reacts to other objects or pedestrians encroaching on the field, whether standing still or moving. There is also the field of the other driver, the other driver’s sense of where her field of safe travel is. (Gibson & Crooks, 1938)

The lens model (Brunswik, 1955) proposes what we think about the environment as reflected in the distal and proximal cues. Previous experience then sets the weight of the cues, even which ones are looked for. The cues are also compared with the outcome which can alter the weight of the cues. The perceptual cycle (Neisser, 1976) also proposes the idea that the actual world modifies a person’s internal representation, his schema, which then directs the perceptual exploration that samples the actual world. In other words, perception is an active process.

In the RPD model (Klein, 1999) the idea that decision making can be made through recognition of cues is presented. A decision maker can recognise certain cues as being part of something they have seen before which then mixed with experience can provide a specific solution. The change blindness theory (Rensink et al, 1997) in turn states that focused attention is necessary in order to observe change; there is no complete internal representation.

The drivers’ previous experiences direct how and if they will react to pedestrians they feel may possibly encroach upon their field of safe travel. By this, all drivers do not react in the same way to pedestrians. Also, since perception is anticipatory and selective, drivers direct their attention to certain parts of the available perceptual field, whereby the driver may become blind to changes in other parts of the perceptual field. The influence previous experience has on perception is accounted for in the perceptual cycle, where the driver’s schema is modified according to occurrences in the “real” world, and the schema also directs which action will be taken in a situation.

In the RPD model, the decisions made are explained by the driver having matched the cues in the ongoing experience to earlier experiences, and then reaching a decision by taking the solution that is good enough to work from the earlier experiences of making decisions in similar situations. According to the lens model, there are distal cues in the world that are given a worldly explanation such as “safe” or “dangerous” (proximal cues), and the selective nature of perception is explained by the cues not being given the same equal importance, due to experience. The selective nature of perception is explained by the perceptual cycle by the schema controlling what is primarily attended to in a situation. In the change blindness theory, the fact that changes in the perceptual field can go unnoticed is explained by the driver only directing his or her attention to certain parts of the available cues, not having a complete internal representation of the world.

According to the lens model it may be possible to identify the distal cues drivers use in order to determine which pedestrian might be an obstacle, since they exist in the world.

1.3 Pedestrian behaviour and pedestrian detection

There are some systems for pedestrian detection today, simple measure-based ones, or ones using models based on statistics on how pedestrians move. Regarding models or theories concerning pedestrian behaviour, there are models both based on how
pedestrians move statistically without taking into account the environment, and models on how pedestrians move as a group but not individually.

1.3.1 Measure-based systems
There exist a variety of measure based systems; here two are presented in more detail, the Honda Intelligent Night Vision system, and the PROTECTOR system.

1.3.1.1 The Honda Intelligent Night Vision system
The Honda Intelligent Night Vision system, commercially available in Japan since January 2005, tracks and detects pedestrians in the path of the vehicle and calculates their trajectories and positions. The system monitors wheel speed and yaw rate; it also has a daylight sensor and an ambient temperature sensor. The camera monitors the road within a 12° arc and provides auditory and visual alerts using a head-up display. The system measures distance by stereo vision and shape recognition, and is capable of providing alerts 30 to 80 meters ahead of the vehicle. The Intelligent Night Vision system provides an alert when a pedestrian is in vehicle's path or approaching the vehicle's path. It also gives an alert for pedestrians walking along the side of the road, even if the vehicle travels close to the centre line. The vehicle’s path is represented by the car’s breadth within the 30-80 m area (Honda’s patent, 2004). The system is on the website (Honda) only showed detecting pedestrians on country roads, with one or few pedestrians at a time on the road.

1.3.1.2 The PROTECTOR system
Another example of a pedestrian detection and warning system is the PROTECTOR system, part of an EU research project by DaimlerChrysler Research (Gavrila et al, 2004). The PROTECTOR system is intended to itself stop or slow the car down in the event of a possible impact. The PROTECTOR system calculates trajectories and warns the driver for all pedestrians entering a zone from 5 meters in front of the vehicle to 25 meters ahead of it, which to the PROTECTOR system is the significant zone. It uses two cameras, each with a 30° angle, and has been tested on real roads in Germany, both with actors and “ordinary” pedestrians, the car being driven at a speed of 30 km/h. Gavrila et al do however not see this system as being implemented soon; they say more research is needed. (Gavrila et al, 2004)

1.3.2 Statistically based system
The Markovian model of pedestrian behaviour (Wakim, S. Capperon, J. Oksman, 2004) is a statistical model of pedestrian behaviour, based on a four discrete states Markov chain. The states are “standing still”, “walking”, “jogging” and “running”, all taken from pedestrian paces. As can be seen in the figure below (fig. 6), not all transitions are possible. It is for example not allowed to go from jogging to standing still without having walked, or from walking straight to running without having jogging. In this model of pedestrian behaviour the current pedestrian pace is calculated given the former one. This is then used to give a speed vector with a norm and an angle, which in turn follows the present state. The behaviour of all pedestrians is calculated individually.
The aim of Wakim et al is to develop a system that calculates the pedestrian and vehicle trajectories respectively and through that can predict the risk of impact, it is however not yet a working system but only a proposal.
1.3.2.1 Other pedestrian detection and behaviour models

Hoogendoorn et al (2003) describe pedestrian behaviour as a group, on town squares etc., and do not describe pedestrian behaviour on a single person level. Many other pedestrian detection systems are only detecting pedestrians, not bothering to also see their behaviour. They are only image processing algorithms (Pai et al, 2004; Bertozzi et al, 2003). These systems only identify pedestrians, and are still working on that problem since the trouble of correct identification of pedestrians is a large problem in itself.

1.3.3 Pedestrian detection systems based on cognitive models

No such systems have been found. This is most likely due to a lack of adequate theories or models of pedestrian behaviour or of driver perception. One reason for this could be that cognitive science is a relatively new (established in the 1950’s) research area, and therefore not well known to practitioners in this area, such as programmers and engineers. Also, engineers lack the perspective of a human’s point of view since psychology and engineering have been, and still are to some extent, kept separate. It is also possible, although not very likely, that someone is working on a system based on a cognitive model but that the research is kept confidential.

Markov chain
Pedestrian state transition diagram

The arrows represent transitions between states.
For the sake of simplicity, the designations of those transitions have not been included.

figure 6
2 THE PROBLEM

With almost 2/3 of all pedestrian fatalities, as mentioned previously, occurring in dark conditions something clearly must be done to protect pedestrians in darkness. As mentioned before, a pedestrian might be visible 20-30 meters ahead of the car, whereas the car with its headlights is visible to the pedestrian long before that. This poses a problem that needs to be solved. A solution could be a system that might be able to help drivers discriminate among pedestrians to find the ones with a behaviour that could cause them to be hit or be put to risk of being hit by the car. As shown above under the section heading “Speed”, a reduction in 20km/h from hitting a pedestrian at 50 km/h to 30 km/h reduces the fatality drastically from up to 80% to just 10%, which is why an early warning of pedestrian location or presence is pivotal.

One way of doing so is through a system to make drivers more aware of pedestrians nearby, as the PROTECTOR system and the Honda system do, just by measuring the distance to the pedestrian. However, research leading to those systems (especially the Honda Intelligent Night Vision), is confidential, and no theories can be found with regards to individual pedestrian behaviour relating to drivers. The Markovian model on the other hand explains pedestrian movement, but like the others has no connection to the driver’s experience of the situation.

To some time in the future develop a system that can warn drivers about pedestrians, one first needs to establish which pedestrians actually are worth keeping an eye on, and which are not. Just determining the shape a pedestrian is something to be done by algorithms. To determine which pedestrian is at risk to be hit by the car on the other hand, one needs a system that can discriminate among pedestrians to find the ones that might act in a way that could put them at risk of being hit.

The objective of this study was to relate the pedestrian behaviour to what behaviour a driver actually feels is “risky”, something that needs to be focused more upon. This study aimed to find the cues associated with drivers believing that a certain pedestrian might behave in a way that could cause them to be hit by the driver. These cues will later on be the first findings to be used as a starting point for an intelligent night-vision system.

2.1 Research questions

This study aims to find out if it is possible to:

- find any specific distances at which drivers consider a specific behaviour a risk, and at which distance they do not?
- determine what kind of behaviour causes a pedestrian to be considered unsafe?
- find a way to discriminate among pedestrians who are at risk of maybe being hit if drivers do not react?
- discriminate between pedestrians who will or will not act in a risky manner, based solely upon the pedestrians, not the environment in which they act?

2.2 Limitations

No consideration was taken to what goes on in the pedestrians’ minds, since that is practically impossible; besides it would make this report too large. Other pedestrians’
behaviour around a certain pedestrian were not either taken into account, since the attempt was to see whether it is possible to determine the risk in a more simple fashion first. Other cars or obstacles were not either taken into account. Only pedestrians which could actually be seen were studied, not the places where they could suddenly appear. In short; pedestrians were studied as independent entities, to see whether that type of analysis was possible. Driving only took place on straight city streets, to achieve as simple conditions as possible for this first study, i.e. not having bends in the road or similar conditions.
3 METHOD

This study aims to be hypothesis-generating rather than hypothesis-testing. Therefore, empirical data must be collected, and qualitative data is the preferable type of data to develop a theory since it aims at doing justice to the complex nature of the world, according to Breakwell, Hammond and Fife-Schaw (2000). In qualitative research, focus lies not into seeking to establish a random sample. Qualitative research is concerned with studying particular phenomena wherefore samples tend to comprise a small number of cases chosen on a theoretical basis. Notable is that in qualitative analysis, all facts must be accessible for researchers to return to and perhaps do a different analysis on. (Breakwell et al, 2000)

In some psychological studies, it is risky to tell the participants everything about the study, since that may alter critical aspects of their behaviour. However, it is of course not very ethical to withhold information, which is why it is suggested that the researcher first see if deception is at all to be considered by for example asking colleagues. If some kind of deception is thought to be the only way, the participants should be debriefed at the earliest opportunity according to the British Psychological Society (BPS) ethical principles (reported in Breakwell et al, 2000). A self-report method such as interviewing relies upon respondents being able and willing to give complete and accurate answers to the questions posed. Even if they wish to cooperate, they may not remember the details requested or not understand the question.

According to Breakwell et al (2000), a systematic set of questions reduces the risk of inaccurate or incomplete answers in the interviews. If the answers then are consistent they can be used in validity checking, data that fall outside the others can be excluded. One risk in using interviewing as a method is that a very large amount of data will be collected, and it is necessary to reduce it to a manageable size. The immediate advantage of writing the answers down is that the workload is reduced. A disadvantage of writing the answers down immediately is nonetheless that the answers have been filtered already, without having the initial data to compare with. The advantage of recording the interviews is that the initial selections can be revised later, even though the amount of material is greatly increased. (Breakwell et al, 2000)

For the analysis of qualitative data, Breakwell et al suggest using the data-display method where all data is presented in a focused manner. This is done in a way that comparison can be made, differences and themes can be found. Data is coded in at least two levels, where the second level consists of the initial codes grouped together to form a theme. It is then possible to draw a “causal network display”, to see if more of one variable (temporally) leads to more of another. I.e. eating leads to a fuller stomach. The data display model is used to establish dependencies. Dependencies can be established by relating occurrences to the temporal dimension, and the fact that the behaviour occurs locally, in one specific setting. Causality can in turn be inferred when there exists, among others, a strength of association, consistency, specificity, temporality or coherence (Miles and Huberman 1994:146 in Breakwell et al, 2000)
3.1 Chosen methods
Methods chosen are data recording via a moving vehicle and data recording using a stationary camera, as well as interviewing. Data have also been analysed using parts of the data-display model.

3.2 Apparatus
For stationary video recording, a digital video camera was used. For recording through a car window, a specially equipped Volvo V70 (2001) from Autoliv where a black and white video camera with a 36 degree field of vision, speed recording via GPS and a laser-radar with a sweep frequency of 12Hz and a 200 degree field of vision to measure distance were used among the systems in the car (fig 7). The camera was located in approximately the same height as the driver’s eyes underneath the rear-view mirror, and the radar was fastened just to the left of the registration plate on the front bumper, in front of the driver’s seat.
A Windows lap top computer with MATLAB was used to present video recordings to participants in the study. GPS data were not used, but the GPS affected the appearance of the car.

3.3 Participants
Professional drivers consisting of five driving instructors and three taxi drivers participated. Of these, two driving instructors and one taxi driver were from Norrköping (neighbouring town), the others from Linköping. Selection of the participants was done on a basis of which were available and volunteered to participate.

3.4 Procedure
The study consisted of two parts, camera recording of pedestrian behaviour and interviews with participants.
3.4.1 Camera recording
Recording took place on weekdays in November, no school holiday, from about 13:00 until about 15:00 in Linköping, since it at that time became too dark for the cameras.

3.4.1.1 With the stationary camera
Pedestrian behaviour was recorded at streets in Linköping’s inner city, at zebra crossings with and without light indication. The camera was positioned on a tripod along the same streets as the car was driven, with the main view over the zebra crossings. Parts of the sidewalk were also in the view of the camera for longer recording of the pedestrians (fig. 8).

![Example of the view from the stationary camera](image)

3.4.1.2 Through the moving car
The car was driven through central parts of Linköping, according to reports on pedestrian accidents from the Linköping municipality (Linköpings kommun gatuenheten, 1998-2002), and mapped out so as to get a path that was easily driven. An example of the footage can be seen in fig. 9, below.

![An example of the footage](image)
3.4.2 Interviews

Interviews were only conducted on the video recordings from the mobile camera, and done in two parts. Participants were interviewed one by one. Both parts of the interviews were conducted at the same occasion in the order displayed below. Before the interviews, participants were informed that the study was related to pedestrian behaviour in traffic, and that it was a MSc-thesis. Only after the interview had finished was the full aim of the study told to participants.

A pilot study resulted in the amount of video recording shown being slightly reduced to reach a maximum interview time of 40 minutes in total; the questions were also slightly clarified.

3.4.2.1 Pre-selected pedestrians

The first part of the interview contained video recordings of pedestrians who behaved in a way the researcher felt could be difficult to determine, some could be considered a risk and others not. Nine different pedestrians in different footage were chosen, and the recording was forwarded until they could first be seen. The recording was shown until the pedestrian was out of view of the camera. Questions were asked to find out why the participants would or would not have considered the pedestrians indicated by the research leader as being a risk, and if they would change their opinion following the behaviour of the pedestrian/-s. Answers were written down by hand by the researcher. The aim of this part of the interview was to determine why some pedestrians were not considered risks.

Questions were:
Would you consider [specification of pedestrian] a risk?
Why / why not?
How can you be sure?
If you would, when would you stop considering them a risk?
Why?

3.4.2.2 Pedestrians selected by participants

The second part of the interviews was done with five of all video recordings chosen, with a total playing time of 2 minutes 50 seconds. Video recordings were chosen on the grounds that they must complement each other, with a large diversity of behaviours, but still not be as many as to bore or tire the participants. Video recordings also contained a speed bar at the bottom left part of the footage, in the cases where GPS data had been available. The image was trimmed in height from the original 27 degrees to about 18 degrees to reduce the amount of sky and road in the image.

The video recordings were shown to participants on a player in MATLAB (fig. 10), where the subjects were allowed to stop the recordings themselves by clicking with the mouse on the recording, when someone in particular caught their attention more than other pedestrians. The participants could stop and continue the video recording when they found it necessary.

When the recording was stopped, a pop-up box with questions appeared on the screen, and boxes to be written in also appeared. Answers were logged in a text file for
analysis. Participants freely communicated what they thought, question by question, and answers were written down on the computer while the participant talked. The participants were not allowed to type the answers themselves. If the participants felt what they said had been misrepresented, they had the opportunity to ask to have the text changed. When all questions had been answered, the video recording could be continued from that same point again. If the participant felt she/he had been mistaken about whether to stop the recording, she/he could cancel the questions, and continue watching it. The aim of this part of the study was to determine why a pedestrian is considered a risk.

Questions were:
Who did you focus your attention on?
Why?
What do you think that person/those persons will do next?
Why?

3.4.3 Processing the data

The collected video recordings were played back numerous times to document the behaviour of the pedestrians in them. Video recordings were in digital format to allow for easy scrolling on a computer. See appendix 1 for an example of how the observation of pedestrian behaviour was documented.

Stationary data:
Processing of the recordings from the stationary camera was performed after all interviews on the mobile video recordings had been conducted, to ensure a deeper understanding of the research area.
All pedestrians possible to track were observed. Their behaviour was monitored over time, the factors used were speed, acceleration, angle in reference to the road and whether the pedestrian crossed the street or not. The behaviour of the pedestrian was then compared to whether the pedestrian crossed the street or not to see if any behaviour gave a correlation.

Interviews:
- Pre-selected pedestrians
  All statements were divided into statements regarding a reaction, and statements regarding no reaction. These were then compared to see if there was a difference in the behaviours stated for a reaction versus no reaction.
- Pedestrians selected by participants
  All pedestrians were observed closely. Any pedestrian reacted to was considered “risky”, regardless of how many participants reacted to them.

The behavioural factors studied were distance, side of the street, placement, speed, angle in reference to the street and acceleration. Pedestrians were categorised as ones reacted to and not reacted to, after which a very crude selection was made to determine if any one factor was decisive. When side of the street, placement, angle and acceleration were found to be partly decisive these were looked into more closely. Since placement on the sidewalk was something mentioned by the participants earlier on in the study, it was selected as the theme. Then an attempt was made to find out if these factors were enough to separate which pedestrians trigger a reaction and which do not. The measure of distance was also documented to give a specific measurement of which side of the street the pedestrian was on, as well as where on the sidewalk the pedestrian was. Figure 11 shows the display used by the researcher to determine distances. The rectangle at the bottom right part of the picture is the car, with the approximate camera angle drawn into the radar plot. Distance is shown in meters, the grid being marked at 1 and 5 metres. Distance is measured from the grill of the vehicle, in front of the driver’s seat (just left of the registration plate). The distance measurements were not shown to participants.
3.5 Pilot study

A pilot study was performed to see whether the questions were posed correctly so answers were complete and true, and if information given in the beginning of the interviews was sufficient.
4 RESULTS

4.1 Stationary camera
The behaviour of 83 pedestrians recorded at four different pedestrian crossings, two with and two without lights, was broken into five observable factors. Behaviour observed was angle to the street, crossing/not crossing the street, acceleration, speed and placement on the sidewalk.

4.1.1 Angles
Measurement of the angles was subjective, and angles were divided into one of three categories; small angle, large angle and right angle. A small angle was one significantly smaller than 45 degrees, large angle about 45 degrees and above. If the angle was close to 90 degrees, it was determined to be a right angle. All angles are in relation to the edge of the sidewalk. The determining of the angles was partly helped by the perspective provided by the paving stones.
Angles below (fig. 12) illustrated as pedestrians walk into the picture, example of a small angle, a large angle and right angle.

Pedestrians walking at a right angle towards the street crossed the street in 35 cases of 38. When considering the pedestrians walking along the street there were 9 additional observable behaviours except “small angle to/from”, “straight ahead” and “large angle to/from”. These nine other behaviours all were composite, such as “walking at an angle towards, then walking straight, then walking at a smaller angle towards”. No composite behaviours turned out to have a big influence on crossing or not crossing the street.
All pedestrians observed who ever walked in a small angle toward the street crossed however. None of the pedestrians ever walking in a small angle away from the street crossed. Example of pedestrian behaviour, see figure 13.

### 4.1.2 Acceleration, speed and placement

People who walked parallel to the street and slowed down as well as people who walked at a right angle to the street and slowed down, normally crossed the street (24/25 of the two cases mentioned above), 21 of these 25 also stopped before crossing. The ones maintaining the same speed had a ratio of 31 of 51 total pedestrians maintaining the same speed crossing. Out of the 9 people walking slowly, seven crossed. Of the 12 people walking fast, 8 crossed.

Placement on the sidewalk was not very important to determine whether the pedestrian crossed or not, about the same amount of pedestrians walking on the inner part of the sidewalk crossed as did not cross. The same applies to walking on the outer part of the sidewalk. For further information, see appendix 2.

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*figure 13
Two examples of pedestrian behaviour. Left, pedestrians crossing the road, right, other types of pedestrian behaviour*
4.2 Interviews

The analysis of the interviews has been divided into two parts, since the part where pedestrians were pre-selected contained speculation on the part of the participants.

4.2.1 Pre-selected pedestrians

These results describe how the participants thought they would react upon the pre-selected participants, not what the participants actually would do. Results have been divided into pedestrian behaviour and environmental factors. Different situations were reacted to differently, the participants’ answers only reached consensus in two cases. Therefore, several situations resulted in both a reaction and no reaction; the participants in their answers also quoted different aspects of the situation as the ones which they found were decisive.

Reasons given by participants not to react to a pedestrian:

o Behavioural factors
  • “Moves slowly or stands still.”
  • “Is located far from the side of the road.”
  • “Is taking distinctive steps in the middle of the sidewalk.”
  • “Walks along the inner edge of the sidewalk.”
  • “Did not look toward the street.”
  • “Is walking far to the right [when on the right side].”

o Environmental factors
  • “Waits for the bus.”
  • “Is pushing the button for the signalised zebra crossing.”

Reasons given by participants to react to a pedestrian:

o Behavioural factors
  • “Did not look toward the car even though the pedestrian is directed towards the street.”
  • “Moves towards the street.”
  • “Just glances at the car.”
  • “Takes resolute steps toward the street.”
  • “Walks a little bit too fast at a right angle toward the road.”

o Environmental factors
  • “Hasn’t passed the zebra crossing.”
  • “It’s a shopping street.”
  • “You just do not know even though the light is red for the pedestrian.”
  • “Groups are difficult to monitor.”

4.2.2 Pedestrians selected by participants

Some reactions were omitted from the results due to the participants reacting to situations without pedestrians, such as the possibility of someone walking out behind a bus.
The reasons why the participants reacted to the pedestrian/pedestrians and what they thought the pedestrian would do next are explained below. The reason why the participants thought the pedestrian would act in a certain way overlapped with why they reacted to the pedestrian, wherefore those answers have not been included.

Reason to react:
In 43 of 83 total answers the behaviour of the pedestrian was the cause of reaction. The road was mentioned in 7 cases of those 43 as a reason to react, someone either being on the road or on their way out on the road. In 30 cases of the 83 the environment, like other pedestrians or objects being in the way, or the presence of a zebra crossing, was the determining factor. In ten cases either the participants did not know why they reacted, were insecure of why or did not specify a reason to react.

What participants thought the pedestrians would do next:
In just more than half the cases (45 of 83), where the participants did indeed react, they either did not know what would happen, were insecure of what could happen or believed that nothing dangerous would happen. The other 37 cases in which the participants thought something dangerous would happen contain among other things pedestrians who have been prompting a reaction when the pedestrians were already in the street, so these results should not be taken to be as meaningful as the others. The reason for this is that the participants already when they had stopped the video recording could see that the pedestrian was doing something dangerous. These consist of about half the 37 cases where the participants thought something dangerous would happen.

Reaction and lack of reaction to pedestrians:
The pedestrians for whom there had been a reaction by participants were then compared with the pedestrians to whom there was no reaction. The factors usable to analysis were side of street, position on the sidewalk, angle toward street and distance.

- In the street
On every occasion in the video recordings when a pedestrian was in the street, there was a reaction. The reaction was prompted not due to the direction the pedestrian was headed, since some were standing still, but from the fact the pedestrian is on the road. No data on pedestrians standing on the road on the left side was recorded.

- Position on the sidewalk
For explanations, see figure 14 below. Standing still on the middle of the sidewalk prompted no reaction if over 4 m to the right of the car or more or equal to 7 m to the left of the car. There is however an overlap in 3-4 m to the right of the car both prompting a reaction and not prompting a reaction. Distances were measured in the analysis, whereas drivers do not judge distances, but rather perceive risk in terms of time-speed relations such as being too close. Pedestrians on the outer part of the sidewalk were reacted to if they were located less than or equal to 6 m to the left of the car or less than 3 m to the right of the car. Pedestrians on the outer part of the sidewalk to the right located 3 m from the car were however both reacted to and not.
A pedestrian being on the outer part of the sidewalk on the right side of the car can in specific cases be reacted to even if 5 m to the right of the car. There is however no satisfactory explanation for why that specific pedestrian was reacted to.

<table>
<thead>
<tr>
<th>Middle of sidewalk, NO reaction</th>
<th>Outer part of sidewalk, reaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;= 7 m</td>
<td>&lt;= 6 m</td>
</tr>
<tr>
<td>&gt; 4 m</td>
<td>&lt;= 3 m</td>
</tr>
</tbody>
</table>

*figure 14*

Display of pedestrians on the middle (left) and outer (right) part of the sidewalk. Display only shows pedestrians where the sidewalk factor was enough to determine a reaction or no reaction.
○ Angle toward street
Concerning the pedestrian’s angle toward the street (see fig. 15), there was a reaction if the pedestrian was walking at a right angle toward the street and was less than 50 m away on the right side of the road.

*figure 15*
*A reaction concerning the pedestrian’s angle toward the street is prompted if the pedestrian is walking at a right angle toward the street, less than 50 m in front of the car on the right side.*
Distance from the car

Solely comparing the distance from the car to the pedestrian gave a large overlap in when the participating drivers reacted and when they did not. Therefore, distance was coupled with the other observed behaviour as well. Some results regarding distance were however found (see fig. 16), the figure however only displays the extreme values of distance. The furthest distance from the car when there always was a reaction is 45 meters; this is when applied to pedestrians in the road. There is no closest distance of reaction since the exact time of reaction of the participants was not analysed. When concerning the left and right side distance from the car, the furthest distance to trigger a reaction is 7 m to the right of the car and 6 m to the left of the car. The closest distance not to trigger a reaction is 3 meters to the right of the car, and 7 meters to the left of the car.

<table>
<thead>
<tr>
<th>NO reaction</th>
<th>Reaction</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Diagram" /></td>
<td><img src="image" alt="Diagram" /></td>
</tr>
</tbody>
</table>

*figure 16*
Displays minimum distances where there was no reaction (left) vs. maximum distance where there was a reaction (right).
The distances on both pictures are the extremes.
There are some distances that triggered a reaction for which there are no matching examples in the material (shown in fig. 17). These behaviours are:

- A pedestrian standing on the street on the right side of the car, no example on the left side of the car. The distance to the right is at most 7 m (car turning that way), and normally (driving straight ahead) less than 3 m to the right. A pedestrian being on the road in front of the car, maximum of 45 m away.
- A pedestrian moving straight ahead or a little toward the street less or equal to 3 m to the right of the car.
- A pedestrian walking at a right angle toward the street from the right if the distance to the pedestrian is less than 50 m.

**figure 17**
Distances prompting a reaction for which there are no other matching examples in the material.
There is also behaviour that did not trigger a reaction (shown in fig. 18);
- A pedestrian walking straight ahead or standing still more or equal to 7 m to the left of the car.

![Distances NOT prompting a reaction diagram](image)

**figure 18**
*Distances not prompting a reaction for which there were no matching examples in this material*

However, some behaviour is ambiguous, both triggering a reaction and not doing so. These include;
- Standing still 3-7 m to the right of the car.
- A pedestrian walking about 4 meters to the right of the car having appeared from a business entrance.
- A pedestrian walking at a right angle toward the road over 50 m ahead.
- A pedestrian walking straight ahead more or equal to 4 m to the right of the car.

### 4.3 Data selection

Video recorded material considered more relevant than the rest from the mobile camera included pedestrians moving in a manner that by the researcher was considered to not be completely safe in traffic, such as being on the road or walking across the road. Pedestrians suddenly appearing behind trees and other objects were not judged to be as important as pedestrians that could be tracked for longer periods of time. If suddenly appearing pedestrians continued to cross the street they were however deemed important, since they could be tracked for longer. The behaviour recorded from both types of video recordings did not include body alignment or gaze direction, since these factors were difficult to monitor in a consistent manner. Pedestrians in the stationary video recordings were excluded if their behaviour was difficult to monitor, such as many pedestrians passing and obscuring the view.
5 Interpretation of results/analysis

Analysis has been divided into three parts, stationary camera, interviews and stationary and mobile combined.

5.1 The stationary camera

The pedestrian’s position on the sidewalk did not correlate much to whether the pedestrian actually crossed. What has been observed however is that a pedestrian might not always choose to walk a specific part of the sidewalk; he or she might be forced to do so due to obstacles such as other pedestrians, parked bicycles or cars. The direction of movement was however related to if the pedestrian crossed the street or not, any pedestrian that walked toward the street did cross, and any walking away from it did not.

5.2 Interviews

The analysis of the interviews has been divided into two parts, since the part where pedestrians were pre-selected contains the participants subjective opinions.

5.2.1 Pre-selected pedestrians

The vast majority of answers to why the participants did or did not react contained behavioural factors. However, some environmental factors such as the presence of a zebra crossing, signalised or not, also influenced the participants in their assessment of the situation.

Concerning the behavioural factors, moving slowly or moving resolutely in the middle or the inner part of the sidewalk was considered an indicator of “safe” behaviour. Also, not looking toward the street was considered an indicator of safe behaviour. A risky behaviour, on the other hand, to participants was for the pedestrian to be directed towards the street and not looking at the car. Just glancing at the car was also considered risky behaviour. Another was to move towards the street, or to take resolute steps toward the street. Also, to walk “a little bit too fast” at a right angle toward the street was considered risky.

5.2.2 Pedestrians selected by participants

Many classifications resulted in the classes of pedestrians, such as being 4 m to the right of the car, were being considered a risk in some examples but not being considered a risk in others. There are however environmental factors, which can explain why the same distance and placement on the sidewalk can prompt different reactions, and separate the pedestrians into safe and risky pedestrians.

Only measuring distance, there are ambiguities that were to some extent explained earlier on under section 4.2.2 “Position on the sidewalk”. Consequently, the difference lies in where on the sidewalk the pedestrian actually is standing, if very close to the road or on the road, there will be a reaction as mentioned before.

The cases for which that explanation does not suffice such as walking in the middle of the sidewalk 3-4 m to the right of the car, are explained below in this section.
○ Other pedestrians
When considering the pedestrian walking about 4 m to the right of the car after having appeared from a business entrance, the environmental perspective needs to take other pedestrians into account. In one of these cases the pedestrian is occluded by another pedestrian, and probably can not be seen by the participants due to that. If the decisive factor here was that the pedestrian was either obscured or closer to the car needs to be investigated further.

The cases in which a pedestrian walking at a right angle toward the road more than 50 m ahead of the car can be separated by the fact that in the two cases that prompted a reaction, the reason was that there were multiple pedestrians walking across the road from both left and right. In the other case, not prompting a reaction, there was just one pedestrian crossing from the left.

○ Other environmental factors
The pedestrians walking straight ahead 4 m to the right causing different reactions can also be separated by use of environmental factors. Here, in one case there is a zebra crossing straight ahead of the pedestrian, which the pedestrian might attempt to cross. Also, in another case that is different from the typical, the pedestrians include children, of which one is jumping around a little.

5.3 Stationary and mobile combined
Pedestrians walking at a right angle toward the street did cross according to the stationary results. This is something which the participants also reacted to if the distance to the pedestrian was less than 50 m, or if there were multiple pedestrians. All pedestrians walking at a small angle toward the street crossed the street according to the stationary results. The angle in which the pedestrians moved was not observed in the mobile material, but pedestrians walking toward the road being less than or equal to 3 m to the right of the car were reacted to.

The amount of pedestrians crossing after walking on the outer part of the sidewalk was about the same as the ones not crossing according to the stationary material. Here, participants reacted to pedestrians located 4 m or less to the right of the car. Decelerating or walking slowly correlated to crossing the road in the stationary analysis. Walking speed was however not one of the factors in the mobile analysis, but in the first part of the interview participants said that a pedestrian moving slowly would make them consider the pedestrian “safe”.

5.4 Validation
All data included in the results were consistent. One answer in the first part of the interview was excluded due to the participant interviewed misunderstanding the question.

Validating the new findings must be done at a later time, and does not lie within the bounds of a 20-credit thesis. This is however how it can be done:

Some of the situations discovered are incomplete, since some situations are lacking examples on the left side of the road, such as a pedestrian standing on the road on the left side of the car. Other situations have not been separated enough, wherefore more examples are needed. These situations should be completed before going ahead with the work of validating the findings. Then, all situations relevant can be set up and studied in depth using ordinary drivers, not only professionals such as the ones used.
in this current study. Then, a new study set up to test the findings in this current study can be made. If that new study proves the findings incorrect, the research needs to be continued to develop a better theory on pedestrian behaviour and driver reactions in traffic. The exact situations that have been possible to separate can be set up using figurants, by which one can drive past them in the car from Autoliv. The same kind of behaviours should also be set up at a variety of distances from the car, so that it’s not just “walking close to the curb” that’s a trigger, but “walking close to the car”, which is a slightly different matter.

Another way of doing this would be by not having the situations set up by using actors, but rather drive around until all sequences needed had been recorded. The downside of this approach is that all necessary sequences may not be recorded, which would leave gaps in the material. This could be repaired by filling in those sequences with set up situations, which would result in having material that is not consistent. To see if the set up situations are in any way affecting the participants, there should be some situations done both with and without actors. Consequently, having previously set up situations would probably minimise the time needed for collecting full and coherent data.

5.4.1 Generalisation
This study was conducted in Linköping, Sweden. Based on geographical and cultural constraints it is not possible to generalise these findings to other cultures, or even other or larger towns or cities. It would therefore be a good idea to, using the validation situations, do the same study in another, different, town, and also in a different country such as Japan, where the Honda system already is in use to see if the cues put forward by this thesis also holds up in that cultural situation. Regardless of the results here, it would be good to record stationary data to see whether there exist other situations than the ones found in this study.
6 DISCUSSION

The discussion has been divided into results discussion and method discussion, followed by conclusions. In the end of the results discussion the research questions are revisited.

6.1 Results discussion

Two cues found are not directly associated to the environment; these are the trajectory of the pedestrian and the distance to pedestrian in front of the car. Other cues are related to the environment such as distance in regard to the road, distance in regard to the sidewalk, presence of other pedestrians and presence of zebra crossings. Also, seeking contact is a cue quoted by the participants.

These cues were found using the data-display model, somewhat modified though. Cues were found by excluding other cues which did not seem to at all have an effect on whether or not a reaction was prompted. This is coherent with the lens model, which says that all cues that exist do not necessarily map to the real event, but can be false cues. The cues found in this study are all distal cues (Brunswik, 1955) since they need to be measurable in order for a future system to be developed.

6.1.1 The most important part – the width of the road

Gibson and Crooks (1938) stated that the field of safe travel lies within the road, something which seems to be the case. Knowing the extent of the road and where the sidewalk began proved to be the only way to discriminate between why a reaction was prompted at one specific distance from the car, but all others at that distance were ignored. The same goes for the position on the sidewalk, which also is in relation to the road. According to Gibson & Crooks, objects radiate a halo of avoidance that limits the driver’s field of safe travel. The results here clearly show that even a pedestrian clearly not in the road emits such a halo of avoidance to the driver. Like the participants said, not only the presence of a pedestrian who probably will do something risky causes them to react, but also just a remote possibility that a pedestrian might do something risky causes a reaction. These findings are consistent with Gibson & Crooks, in that stationary objects also radiate a halo of avoidance, even though they clearly will not be moving. The pedestrians’ being on the sidewalk having an effect on driver reaction was also effected by the pedestrians being directed/not being directed toward the road, or if they were heading toward the road. This is also related to most pedestrians crossing being directed at the road, and all pedestrians crossing at one time or another being on the outer part of the sidewalk. Pedestrians walking at a right angle toward the road and being less than 50 m from the car prompting a reaction can also be seen in view of the halo of avoidance in Gibson & Crooks, the drivers according to Gibson & Crooks estimate the position of the pedestrian in the future, and therefore consider them as being a risk.

6.1.2 Explaining the cues

A pedestrian encroaching on what would normally be the driver’s field of safe travel causes a reaction in the driver (Gibson & Crooks, 1938). The trajectory of the pedestrians and their distance in front of the car are in turn important cues for the driver in determining whether the pedestrian is a risk, whether the pedestrian will encroach on the driver’s field of safe travel. The participants however reacted to multiple pedestrians passing at a distance at which they do not react to single
pedestrians. This might show that the presence of multiple pedestrians passing makes the possibility of even more pedestrians crossing at the same place go up, enhancing that cue as in the lens model (Brunswik, 1955) and being part of a schema which calls for a different action (Klein, 2000), which in turn causes the driver’s field of safe travel to contract (Gibson & Crooks, 1938). A large number of pedestrians at once were in the first part of the interview said by participants to be more unpredictable since there were more pedestrians to attend to. This might also be the reason for the participants reacting over 50 m ahead to multiple pedestrians crossing, but not to a single pedestrian crossing.

The presence of a zebra crossing had an effect on the participants. This probably is related to them having built up the knowledge that a zebra crossing with people approaching it often results in someone crossing, as the environment modifies the schema in the perceptual cycle (Neisser 1976). Another factor that might have had an effect on the participating driver is the 2001 Swedish law of right of way of pedestrians at non-signalised zebra crossings. This knowledge also modifies the driver’s schema, which could influence the reaction to the presence of a zebra crossing.

Other pedestrians, besides the one being reacted to, influenced what the participants thought about some situations. This was also true of the age of the pedestrians in some cases having an influence on participants’ reactions. These, too, are cues which may have been given an increased importance before, and therefore as in the perceptual cycle influence what the drivers look for.

Important to notice is that participants not only reacted to things they thought would happen, but also to situations that were normally safe but had a remote possibility of evolving into something risky. Therefore, one key for a future detection system is to spot the pedestrians who could, but mostly do not, behave in an unsafe manner. The evaluation of those pedestrians is generally more dependant on environmental factors, the pedestrians can do something else since the possibility exists, but they normally (according to the participants) do not do it. Notable is also that the participants did not react to pedestrians walking slowly, rather considered them more safe, even though the analysis of the stationary material showed that pedestrians walking slowly normally crossed the street.

Also, a pedestrian seeking contact was important to the participants, if a pedestrian did not seek contact the drivers felt that the pedestrian had not noticed the car and therefore behaved in an unsafe way. This is like the field of the other driver according to Gibson and Crooks; if the pedestrian has not seen the car clearly, i.e. the driver has not noticed the pedestrian looking at the car; the driver thinks that the pedestrian’s field of safe travel encroaches unduly upon his own, and therefore considers the pedestrian as constituting a risk.
6.1.2.1 Implementing the cues

A system that would be able to pick out the pedestrians considered risky by drivers would need to be able to (by order of relevance):

- Know where the boundaries of the road is, so to know which pedestrians are located on the road.
- Measure the distance to pedestrians both to the sides and front.
- Determine the trajectories of pedestrians as well as their angle toward the road, to know where the pedestrian is headed and possibly notice pedestrians walking at a right angle toward the road early.
- Predict the path of the car, to know which pedestrians to take into account.
- Know the difference between multiple and single pedestrians, and the significance of that difference.
- Take into account obstacles on the sidewalk that may force pedestrians to change their trajectories.
- Determine where zebra crossings are positioned, and if any pedestrian is headed in that direction.

An example of the rules that can be used is found in figure 19 below.
6.1.3 Validity of the argument

The driver first and foremost needs to have her/his attention on the correct cues, otherwise the cues will not be noticed (Rensink, 1997). The cues are in turn recognised as being part of a familiar pattern (Klein, 1999) and therefore used as the basis of forming a decision based on the previous experience of the driver in question. The decision in turn modifies the inner representation (or schema) of that situation (Neisser, 1976).

The cues found in this report are distal; the drivers’ thoughts about certain environmental phenomena are distal cues they have connected to the proximal cue of danger. The reason drivers connect certain distal cues to a proximal cue is due to their experiences as previously stated (Brunswik, 1955). The outcome of the action chosen then alters the weight of the cues, with some cues coming to be more important than others (Brunswik, 1955).
Consequently, the cues that the drivers use are determined by their experiences in traffic as well as what has been told to them (Brunswik, 1955; Neisser, 1976), which in turn helps the drivers determine which pedestrians are riskier than others. The risky pedestrians are determined by means of the driver being able to focus their attention on the correct cues, which some drivers may not be able to do due to that specific cue not having enough weight in their schema to be noticed.

The way in which the approach presented in this thesis is different to others is that a cognitive approach provides a more extended way of determining which pedestrians to focus on in a detection system. This approach helps to display which pedestrians the drivers actually consider to be more of a risk to them. What the drivers thought they reacted to was however not always the single decisive factor of course, they sometimes quoted the lack of contact with the pedestrian but that factor was only a small part in the determination in which position and trajectory proved to be almost enough. Complete understanding is however not possible without also adding the environmental factors.

6.1.4 The research questions revisited

- Is it possible to find any specific distances at which drivers consider a specific behaviour a risk, and at which distance they do not?

That would be possible, seeing that the results in this study has shown that walking at one distance from the car prompts a reaction, but walking in the same manner at another distance from the car does not. The distances in themselves could be different for different drivers, with the drivers being more or less sensitive to pedestrians. As this thesis has shown, there are distances that can be measured, the correctness those distances and what reaction they prompt in the drivers is however not possible to say without further study.

- Is it possible to determine what kind of behaviour causes a pedestrian to be considered unsafe?

In some cases that can be done, at least such as the pedestrian being in the road, or walking into the road. It depends on the position of the pedestrian, however. A pedestrian on the road is unsafe even if standing still; other behaviours are dependent on the distance to the car and also in relation to the road and the pedestrian’s position on the sidewalk, and the position of the car on the road.

- Is it possible to find a way to discriminate among pedestrians who are at risk of maybe being hit if drivers do not react?

In the dark it is at present not possible to know since this study was conducted in daylight conditions. In daylight conditions however the findings are consistent enough to form hypotheses on, but these need to be validated. According to the findings available now, it should be possible to find the pedestrians at risk of maybe being hit according to the drivers. To what extent however needs to be studied further.
Is it possible to discriminate between pedestrians who will and will not act in that manner, based solely upon them, not the environment in which they act?

This can only be done for some pedestrians, as shown previously. The extent of the road has proven so important in the driver’s determining which pedestrian is a risk that it is very much needed to correctly discern the risky pedestrians.

### 6.2 Method discussion

The two main parts of the method discussion are related to the recordings, the participants and data. Ultimately, the setting in which this study took place was satisfactory to allow the conclusions drawn to be made.

#### 6.2.1 The video recordings

All data were recorded in daylight, even though the idea is also to use these findings for a night vision system in the future. The results found in this study therefore cannot be generalised to dark conditions, since pedestrians or drivers or both may act differently. However, it is not possible to record in the dark and get sequences which can then be used to evaluate which pedestrian one would consider risks since one probably will not be able to see all pedestrians in the area. The reason for recording in daylight is that it provides the easiest way of acquiring initial data, using a simple situation. If it had been impossible to reach any conclusions in daylight conditions, it probably would have been impossible in dark conditions as well.

All data were, as previously mentioned, displayed on a computer, without any feedback to show where the car was headed or if it was to slow down. This could have had an influence on which pedestrian the drivers reacted to since they did not have the possibility of incorporating the knowledge of where the car was headed, so the situation was not fully life-like in such a way. The advantage of having the situations recorded was that all distances were the same to all participants, and all participants experienced the same situations. Therefore it was also possible to select among the sequences to show only some situations, so there was a diversity of situations facing the drivers. It would however be a good idea to conduct a study with participants actually driving at a later time to determine how they would act in a real-life situation.

The streets driven on were selected because of their relative simplicity. This entails that there are situations which this study has not discovered, since they would demand another type of road. Yet, it is preferable to do this initial study using simple material to see whether the problem of identification can be solved there before going into more difficult settings.

The camera recordings were in black and white, not colour, which made the situation less life-like. Unfortunately, this was due to the experimenter not considering this factor in the beginning and therefore not requesting a colour camera for the car. Since pedestrians still move in a manner that is different from that of cyclists and cars, pedestrians can be detected based on their movement, not only by the bright colour of their clothes. Since the study resulted in reactions even though cues associated with colour are missing, the cues related to colour prove not to be necessary since other cues have been proven to be enough for these purposes. It cannot however be said that that the quality of the results had been different or not.
6.2.2 The data and participants

The distances from the laser radar should not be taken to be the “true” distance of risky behaviour, since the camera was mounted in the middle of the car and therefore gave a slightly altered view of where the car was positioned on the road. This somewhat altered the perspective for the participants, which possibly could have affected their judgement of risky pedestrians. Also, there is a measuring and reading fault when reading the distances from the laser radar, since that was done from a graphic representation, displayed in figure 11. The resolution of the laser radar is 30 cm, and the angle resolution is approximately 1.2 degrees at the frequency used. The parallax fault between camera and radar is approximately 0.5 m on the Y-axis (to the left and right of the car), and 1.5 m on the X-axis (in the car’s driving direction), see figure 20. The video recordings also did not have a very good resolution for the participants, which can have had an effect on their judgment of distance. The important part on the other hand is not to determine the exact distance at which behaviour is thought to be a risk, but to note that it is actually possible to determine whether a risk is likely. Also, the parallax is not as noticeable at a larger distance in front of the car since the angles are so small that the parallax probably can be overseen in that situation. Further study is however needed to validate the distances.

Only professional drivers participated in this study in order to access people who on a daily basis determine risks in traffic from a car, and therefore see more pedestrians in a larger diversity of situations than others do. The reason for using driving instructors in particular was the notion that they should be used to communicate cues to their pupils, and therefore might be better at verbalising why they actually acted in the way they did. It would in the future of course be a good idea to test the findings on regular drivers as well, to see if they agree to the notions put forward by the taxi drivers and driving instructors.

Because of the small number of participants from Norrköping, no conclusions can be drawn as to if the familiarity the participants from Linköping had with the streets in the video recordings in any way affected the results.
All pedestrians for which there had been a reaction by any of the drivers participating were analysed. The reason for this is, at this early stage it is not possible to tell which pedestrians are more important than others, and having just eight participants is too few to exclude any of the pedestrians for which there had been a reaction. No qualitative factors were studied, due to it being easier for a night vision camera to register the quantitative factors quoted.

### 6.2.3 Method discussion review

Altogether, it is necessary not only to validate the findings in daylight, but most importantly also in dark conditions to see whether the reactions would be different. It would also be interesting to see whether there was a fault in measuring due to the parallax of the camera and view of the driver. As this was the first study made, the conditions in which it was made can be said to be sufficient.
6.3 Conclusions
Even if these results are not possible to generalise in their detailed state, some more general conclusions can be drawn.
It was not possible to determine if a pedestrian will be considered a risk based merely on the pedestrian’s behaviour and distance to the car. It however became possible to a large extent to do so by also interpreting the behaviour of the pedestrians. Therefore, it is necessary to track and interpret the behaviour of the pedestrian. Information processing alone is not sufficient to develop a system to discover risky pedestrians; the system also needs to have an understanding of the driver’s perception during driving and the active and anticipatory nature of that perception.
It is also vital to note that not only the pedestrians who behave in a way that could put them at risk are considered as risks, but also the pedestrians who could, but probably will not, behave in an unsafe way.
The condition in which this study was made was sufficient for its aim. In future studies however it would be advisable to add more factors such as darkness or bends in the road. It could also be an idea to allow participants to drive for themselves and then record the actual behaviour, such as turning the wheel, slowing down and moving the foot to the brake pedal.

6.4 Further research
Considering the distance to the camera the interesting part would be to know how far from the car someone is considered a risk. Therefore it would be good to study which pedestrians are risks at that same distance from the car and partly if it is possible to determine that further in advance than the drivers can do, i.e. ahead of the 1 second reaction time. It has in this thesis proved possible to separate the pedestrians considered to be more risky than others from the other pedestrians, but whether or not this can be determined far in advance needs to be investigated further when the findings from this thesis have been tested.
It would be a good idea to ask the participants what they would do about the pedestrians they react to, just to see which situations are vital and which can be thought to be of less importance. In this same part it would also be very interesting to know what the results would be if the participants were allowed to drive themselves, and were only given the instruction to drive. Then their actual reaction to pedestrian situations could be monitored, leaving out what the drivers believe they would do. This would however demand similar situations to occur for the results of different drivers to be compared.
No attempt has been made to see when the exact time of reaction was, and what behaviour exactly took place the seconds before that. This would also give more information if combined with what the reaction of the driver would be.
It may well also be a good idea to calculate the mean time one sees a pedestrian in the mobile camera before the pedestrian could have been hit by the car or is passed. This can then be used to know how much time an artificial system would have to make a decision.
Is the same behaviour on behalf of both pedestrians and driver as observed in this study actually mirrored in dark conditions? There is currently no answer for this, it would be interesting to see. The spontaneous answer from drivers when we were chatting after the interviews was that they want to know about all pedestrians around the car, even the ones too far ahead to be an immediate risk to them. Yet, if they mean that they really would be much more sensitive in dark conditions to pedestrians in the surrounding area, are there still pedestrians more important than others? Are the drivers correct? Also, are the pedestrians behaving in a different manner in dark conditions? This clearly needs to be studied further.
REFERENCES


Linköpings kommun gatuenheten (1998-2002), Årsrapporter med trafikolyckor

MATLAB, www.mathworks.com


Volvo cars, http://www.volvocars.com


APPENDIX 1

An example of the notes taken on pedestrian behaviour. This example is taken from the mobile camera recordings.

Swedish original notes:

**Killen som genar över vägen**

Anmärkning: Svårt att se var han kommer från.

Avstånd: Vid 31 sek är han över 50 meter framför bilen, när han tar första steget ut i gatan är han ca 50 meter från bilen.

Följts från resp. passerats: Vid ca 30 sek syns han först, vi har passerat vid 36 sek


Påpekades från – till: 31,4 – 33,6

Antal som påpekade: 7

Translation:

**Guy taking a shortcut across the road**

**Remark:** Difficult to se where he is emerging from.

*Distance:* At 31 sec he is over 50 m in front of the car, when he takes his first step into the street he is about 50 m from the car.

*Tracked from/passed at:* At 30 sec he is visible the first time, the car has passed him at 36 seconds.

*Behaviour:* Is on the left side of the road. Takes long steps, walks fairly quickly. Walks perpendicular to the car’s path. Does not look at the car. Walks at somewhat of an angle out into the street, sort of from the back from the left. When he at first is visible he seems to be positioned on the sidewalk. Then he increases his speed, or maybe he has been walking fast all the time, and begins to take a shortcut across the sidewalk toward the zebra crossing. He takes two strides toward the zebra crossing, and then he begins to walk at more of a right angle (earlier small angle) across the street. Maybe he emerges from a business entrance, it is difficult to see. He then slows down when the car is about 10 m away and he has reached a refuge. He slows down at the same time as his face is directed toward the car.

*Was pointed out from – to:* 31.4 – 33.6

*Number of people who pointed him out:* 7
APPENDIX 2

Analysis of pedestrian behaviour based on stationary video recordings. The total number of pedestrians observed was 83 (54 + 29). Groups were divided firstly into pedestrians crossing (green, C), and pedestrians who did not cross (yellow, N). Pedestrians are divided into the categories below but are kept as part of their groups (crosses / does not cross). The factors shown are walking speed, acceleration, placement on sidewalk and angle toward the street.

<table>
<thead>
<tr>
<th>Crosses</th>
<th>Does not cross</th>
<th>Sum of crossing</th>
<th>Sum of not crossing</th>
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<tbody>
<tr>
<td>C</td>
<td>N</td>
<td>54</td>
<td>29</td>
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<table>
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<th>Walking speed</th>
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<th>Does not cross</th>
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</tr>
<tr>
<td>Normal</td>
<td>4</td>
<td>39</td>
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<td>Slow</td>
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<tr>
<th>Acceleration</th>
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<tbody>
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<td>28</td>
</tr>
<tr>
<td>Both</td>
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<td>0</td>
</tr>
<tr>
<td>Faster</td>
<td>28</td>
<td>1</td>
</tr>
<tr>
<td>Slower</td>
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<tr>
<td>Stops</td>
<td>21</td>
<td>1</td>
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<th>Does not cross</th>
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<tr>
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<td>4</td>
</tr>
<tr>
<td>Far in</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Inner part</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Middle</td>
<td>10</td>
<td>6</td>
</tr>
<tr>
<td>Outer part</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Edge of the sidewalk</td>
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<td>2</td>
</tr>
<tr>
<td>Crosses</td>
<td>Does not cross</td>
<td></td>
</tr>
<tr>
<td>---------</td>
<td>----------------</td>
<td></td>
</tr>
<tr>
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<td>N</td>
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<th>N</th>
<th>C</th>
<th>N</th>
<th>C</th>
<th>N</th>
<th>C</th>
<th>N</th>
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**Angle toward the street**

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<th>Right angle to 35</th>
<th>A sidewalk away from the street</th>
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<th>N</th>
<th>Small angle to</th>
<th>Small angle from</th>
<th>Straight</th>
<th>Large angle to</th>
<th>Large angle from</th>
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<tr>
<td></td>
<td></td>
<td>Right angle to, walks away</td>
<td>5</td>
<td>6</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td></td>
<td></td>
<td></td>
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<table>
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<th>N</th>
<th>C</th>
<th>N</th>
<th>C</th>
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<th>C</th>
<th>N</th>
<th>C</th>
<th>N</th>
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</thead>
</table>

**Angle, straight, more angle to**

<table>
<thead>
<tr>
<th>Large then small to</th>
<th>Against, away against</th>
<th>Away, Against</th>
<th>Against, away</th>
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<td>5</td>
<td>2</td>
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<td>1</td>
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<tr>
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<th>N</th>
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</table>

**Angle, straight, more angle from**

<table>
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<tr>
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<th>Against, straight</th>
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<tr>
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<td>1</td>
<td>5</td>
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Pedestrian detection and driver attention - cues needed to determine risky pedestrian behaviour in traffic

Annika Larsson

The purpose of this thesis was to determine which perceptual cues drivers use to identify pedestrians that may constitute a risk in traffic. Methods chosen were recordings of pedestrian behaviour in Linköping by means of a stationary video camera as well as video camera mounted in a car. Interviews on the recordings from the mobile camera were conducted with taxi drivers and driving instructors.

Results include that drivers not only react to pedestrians they believe will behave in a dangerous way, but also react to pedestrians that probably not will behave in such a way, but where the possibility still exists. The study concluded that it was not possible to determine how risky a pedestrian is considered to be by only using behavioural factors such as trajectory or position on the sidewalk, and distance. It is necessary also to include environmental factors, mainly where the pedestrian and car are positioned in relation to the side of the road, so that the behaviour of the pedestrian can be interpreted.

Nyckelord

traffic safety, pedestrians, pedestrian detection, night vision, driving