

Health risk aspects and comfort of infants in infant seats for cars

Malin Nilsson

Förord

Föreliggande studie har utförts som ett examensarbete på civilingenjörsutbildningen Teknisk fysik och elektroteknik vid Linköpings universitet under våren 2005. Examinator vid LiU har varit Tomas Strömberg och handledare vid VTI har varit Thomas Turbell. Arbetet är även publicerat vid Linköpings universitet med nr: LiTH-IMT-EX- -05/399--SE.

Från VTI vill vi framföra ett varmt tack till Malin Nilsson för ett gott och trevligt samarbete som resulterat i en rapport som kommer att kunna lugna oroliga föräldrar och därmed öka säkerheten för små barn i bil.

Linköping juni 2005

Thomas Turbell

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Malin Nilsson

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Infant safety seats – the child safety seats for the youngest children, from newborn up to 13 kg have saved many lives since they became available in Sweden in the beginning of the 80s. Since then has the question if there is any long-term health effects on infants in car seats been current.

The purpose of this study is to describe the basis for the statements regarding long-term health effects of letting infants sit longer periods in infant safety seats. To find out more about the vibrational environment and comfort in infant seats, vibration measurements are performed in infant safety seats installed in three different ways.

A literature study and interviews with pediatricians, nurses and physiotherapists show that a recommendation including a specified time is not relevant.

Vibration measurements shows that the infant safety seats in contrast to automobile seats amplify vibrations with frequencies between 1 and 25 Hz.

Nyckelord

Keyword

Infant safety seat, health risk, comfort, vibrations

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Sammanfattning

Babyskydd – den minsta bilbarnstolen för barn från nyfödda till 13 kg (alternativt 10 kg) har räddat många liv sen de började hyras ut på BB i början av 1980-talet. Sedan dess har diskussionen, om det är farligt för de allra minsta barnen att sitta i de här stolarna långa perioder i sträck, funnits.

Syftet med denna studie har varit att försöka kartlägga varför det skulle vara farligt att låta spädbarn sitta i de här stolarna och varifrån dessa uppgifter kommer. Studien innehåller även vibrationsmätningar i babyskydd monterade i bilen på tre olika sätt, för att ta reda på om vibrationer skulle kunna ge briser i komfort i babyskydden.

Litteraturstudier och intervjuer med barnläkare, barnsjuksköterskor och sjukgymnaster visar att en rekommendation som anger en viss tid inte är relevant. Det är viktigare att lyssna på barnets signaler och ta en paus när barnet skriker. Liksom vuxna mår inte barn bra av att vara i samma ställning långa perioder i sträck, men det motiverar inte en rekommendation innehållande en specifik tid för ett krocksäkert babyskydd. Undersökningar gjorda i USA har visat att syreupptagningsförmågan minskar med tiden i babyskydd. Det är viktigt att barnet har rätt position så att babyskyddet ger stöd för hela ryggen för att inte stoppa andningsvägen.

Vibrationsmätningar visar att babyskydden i motsats till bilsäten förstärker vibrationer med frekvenser mellan 1 och 25 Hz. Babyskyddet fäst på det nya sättet att fästa bilbarnstolar i bilen med ISOFIX-fästen i bilen dämpar frekvenser upp till 15 Hz bättre än babyskydd som späns fast med bilens säkerhetsbälte, men frekvenser mellan 15 och 25 Hz förstärks kraftigt.

Abstract

Infant safety seats – the child safety seats for the youngest children, from newborn up to 13 kg (or 10 kg) have saved many lives since they became available in Sweden in the beginning of the 80s. Since then has the question if there is any long-term health effects on infants in car seats been current.

The purpose of this study is to describe the basis for the statements regarding long-term health effects of letting infants sit longer periods in infant safety seats. It is desirable to find a correct recommendation for the use of infant safety seats according to made observations and research. To find out more about the vibrational environment and comfort in infant seats, vibration measurements are performed in infant safety seats installed in three different ways.

A literature study and interviews with pediatricians, nurses and physiotherapists show that a recommendation including a specified time is not relevant. The most important is to listen to the child and take a break during the ride when the baby cries. Children and adults do not feel good if they have the same position for long periods, but that does not motivate a time recommendation for an efficient infant safety seat when it comes to saving lives. Studies in USA have shown that the oxygen desaturation decrease with the time spent in an infant seat. It is important that the baby has the right position so the infant safety seat gives a proper support for the whole back and do not block the airways.

Vibration measurements shows that the infant safety seats in contrast to automobile seats amplify vibrations with frequencies between 1 and 25 Hz. The infant safety seat attached with ISOFIX damp frequencies up to 15 Hz better then the infant seats fasten with the vehicle's safety seat, but frequencies between 15 and 25 Hz are strongly amplified.

Preface

This Master of Science thesis project is the final part of the educational program in Applied Physics and Electrical Engineering with focus on Biomedical engineering at the University of Linköping. The work was proposed by and carried out at VTI, the Swedish National Road and Transport Research Institute. VTI performs applied research and development aiming to contribute to the national transport policy objective for sustainable development.

Thomas Turbell at VTI has been my supervisor and Tomas Strömberg, the Department of Biomedical Engineering, at Linköpings Universitet, has been my examiner.

Car safety seat glossary and abbreviations

Air Bag	A passive (idle) restraint system that automatically deploys during a crash to act as a cushion for the occupant. It creates a broad surface on which to spread the forces of the crash, to reduce head and chest injury. It is considered “supplementary” to the lap/shoulder belts because it enhances the protection the belt system offers in frontal crashes (Also known as SRS - supplemental restraint system; SIR - supplemental inflatable restraint; SIPS - side impact protection system; IC - inflatable curtain; SIAB - side impact air bag).
Base (of a child seat)	The base of a child seat is the lower portion that rests on the vehicle seat. A detachable base that comes with many infant seats is used to permit a fixed installation into the vehicle allowing the child seat to be taken in and out of the vehicle without having to do a new installation each time.
Car-bed restraint	A restraint system that positions the infant perpendicular to the direction of vehicle travel. The baby lies flat.
Car Seat	Common term for a specially designed device that secures a child in a motor vehicle, meets federal safety standards, and increases child safety in a crash.
Child restraint systems (CRS)	Restraining devices for child occupants of power-driven vehicles
Child Safety Seat/Child Restraint	A crash tested device that is specially designed to provide infant/child crash protection. Any product which provides a safe environment for children during a crash. A general term for all sorts of devices including those that are car beds rather than seats.
Child safety seat for infant	A type of child restraint system that is specifically meant for use by children from birth up to either 10 kg or 13 kg, used in the rear-facing mode only.
Children with special needs	Children whose physical, medical, or behavioural condition that can makes the use of particular, often specially-designed, restraints necessary.
ECE	Economic Commission for Europe

ECE R44	Child restraints (baby seats, child seats, booster seats and booster cushions) must conform to the ECE Regulation R44.03. Includes measuring of breast accelerations in frontal impact, rear impact and overturning.
FMVSS	Federal Motor Vehicle Safety Standard
FMVSS 213	USA standard that pertains to all restraint systems intended for use as crash protection in vehicles for children up to 50 pounds.
Forward Facing Child Restraint	A restraint that is intended for use only in the forward-facing position for a child at least age one and at least 20 pounds up to 40 pounds. Not common in Sweden.
Frontal Air Bag	A frontal air bag is one installed in the dashboard.
Infant safety seats	A restraint designed for use only by a baby (Weighing less than 10-13 kg) in a semi-reclined, rear-facing position.
NTF	The National Society for Road Safety is a non governmental organisation which works to improve road safety (In Swedish: Nationalföreningen för Trafiksäkerhetens Främjande).
Passenger-Air Bag:	An air bag that is in the right front part of the passenger compartment. It is larger than the driver bag and would restrain either centre or right-front occupants. Air bags are a supplement to the use of seat belts and designed to protect adult occupants in frontal crashes.
Rear-facing infant restraint	A system that positions the infant in line with the vehicle and its back toward the front of the car.
Whiplash Injury	An injury to the neck usually caused by sudden whipping of the head backward during a rear impact collision.

Medical glossary

Apnea	The Greek word Apnea literally means "without breath." Episodes of respiratory pauses.
Bradycardia	Conditions in which the heart beats at an unusually slow rate. For adult it is defined as fewer than 50 per minute, for infants it is defined as fewer than 80 or 90 beats per minute.
Flexion	A movement that decrease the angle between bones
Low birth weight infant	Infants who are born weighing less than 2500 g
Oxygen desaturation	Measures the percentage of hemoglobin binding sites in the bloodstream occupied by oxygen. A SaO ₂ value below 90% is termed hypoxia.
Pulse oximetry	Pulse oximetry provides estimates of arterial oxyhemoglobin saturation (SaO ₂) by utilizing selected wavelengths of light to noninvasively determine the saturation of oxyhemoglobin (SpO ₂)
Premature infant/ Preterm infant	Infants who are born at < 37 weeks' gestation
Posterior	The direction toward or at the back of the body; behind
Scolios	Scoliosis is a condition that causes the spine to curve to the left or right side. Scoliosis can develop during childhood or adolescence. The changes scoliosis causes can happen slowly over time or more quickly as the child goes through a growth spurt.

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1 Introduction

An infant safety seat is the smallest child safety seat for newborn up to 10/13 kg. Parents to newborns may hear statements that say for how long time they can let their newborns sit in infant safety seats in cars the first months without any health problems for the baby. The time lengths vary between 20 minutes per day to 2 hours per day. These statements make the parents worried about their babies when they want to go for a longer ride with the car.

The question if there is any long term health effects on infants in car seats has been current on and off since the begin of the 80s when maternity hospitals started to rent out infant safety seats. The semi-upright position the babies have in infant safety seats before they are able to sit by themselves causes worry. The infant safety seats have been developed over the years, to give proper support for the back. Could the position lead to back problems, or problems with breathing?

Knowledge of long-term health effects on infants in car seats needs to be deeper. Parents have a right to become correct and impartial information from maternity wards, child health centres and other child safety experts, how they best protect their children in car. It is desirable to find a correct recommendation for the use of infant safety seats according to made observations and research.

The efficiency of the infant safety seats to protect lives is well documented. The safety for infants and children in cars has increased marked since the rear-facing child safety seats and the infant safety seats were introduced. But the most important is the use of them, and to use them correctly. Studies of fatal accidents with children involved have shown that one third of the killed children would have survived if they had been placed in a correctly used child restraint system. Statistics over death injuries with children as passengers between 1972 and 2004 (Official statistics from Statistiska Centralbyrån, SCB) shows the efficiency. Before infant safety seats become available and common used in Sweden (between 1972 and 1982), the number of children under 1 year killed in traffic accidents was on average 2,8 (3) per year. Between 1983 and 2004 the number of children under 1 year killed in traffic accidents was 0.91 (1) per year and many of them were not correctly placed in a child restraint system. With an infant safety seat, the risk of death by an accident decreases with up to 95 % (Folksam, NTF).

Vibrations could be a source of discomfort and a risk to human health. Comfort is important when designing automobile seats. They must reduce vibrations effectively. Little is known about the vibrations transmitted from the car to a child fastened in child safety seat.

1.1 Purpose

The purpose of this study is to describe the basis for the statements regarding long-term health effects of letting infants sit longer periods in infant safety seats.

To find out more about the vibrational environment in car seats for infants, vibration measurements are performed in car seats for infants installed in three different ways; the traditional installation with the car's seat belt, installation with a base and the new ISOFIX installation.

1.2 Delimitation /Boundaries

This Master of Science thesis project is the final part of the educational program in Applied Physics and Electrical Engineering with focus on Biomedical engineering at the University of Linköping. The work was made during 20 weeks, proposed by and carried out at the Crash Test Laboratory of VTI, the Swedish National Road and Transport Research Institute.

The literature review is a compilation of existing research and knowledge in this area. The selection of medical experts consulted about health effects is made random. Some of them have recommended other pediatricians or nurses skilled at this topic. The practical part of this work is vibration measurements in different combinations of cars and infant safety seats with suitable equipment.

1.3 Outline of the thesis

The thesis is divided into two parts. Part 1 contains the investigation of possible long-term health effects on infants in car seats; Part 2 contains the vibration work. Chapter 2 is intended to give the reader the background theory for child safety. The method for part 1 is described in chapter 3 and the results from part 1 can be found in chapter 4 and 5. Chapter 6 gives the background theory for vibrations, Chapter 7 contains a method description for the vibration measurements and the results from the measurements are presented in chapter 8. The last chapter, 9, contains a discussion for both part 1 and 2. Appendices are included at the end of the thesis containing, search terms used in the literature search, questions to medical experts, references for possible reasons why the time spent in infant seats would be limited and results from the vibrations measurements.

Part 1

2 Background - Child safety in cars

Automobile travel is a part of everyday life that begins in early infancy (Anund et al. 2003A). Child restraint systems (CRS) include products, which serve to provide a safe environment for children during a crash.

2.1 The Swedish law

In Sweden the use of an approved child restraint system when travelling in a car is mandatory until the age of six years. According to the law (SFS 1998:1276 chap. 4, §10, Notisum) it is the driver's responsibility to make sure that all passengers younger than 15 years old are restrained during the ride.

2.2 To protect children in car

There is a European regulation for child safety seats, ECE R44/03. Every child safety seat on the European market has to be approved and labelled according to ECE R44/03. In Sweden, Vägverket (The Swedish Road administration) issues this approval after compliance tests by VTI, the Swedish National Road and Transport Research Institute.

By designing child restraint systems it is important to take the children's anatomy to account. They are not miniature adults and they are not a homogenous group. Therefore restraint systems have recommendations after weight. Table 1 shows the different weight groups in ECE R44/03. Restraint systems for children comprise rear-facing infant seats, rear-facing seats, and forward-facing seats, booster seats and booster cushions. The focus in this master thesis lies on the child safety seats for newborns.

Table 1. System of groups in ECE R44/03 to define weight limits for child safety seats.

Group	Installation	Child weight (kg)
0	rearward facing	0-10 kg
0+	rearward facing	0-13 kg
1	rearward/forward facing	9-18 kg
2	rearward/forward facing	15-25 kg
3	forward facing	22-36 kg

2.3 Anatomy

Children, in general are more exposed, to increased risks of fatalities and serious health losses in the traffic system owing to several factors (Evans 1991), one is their anatomy. Infants and children have different body size proportions, muscle bone and ligament strengths than adults (Huelke 1998). The Skeleton changes throughout life, but the changes in childhood are most dramatic. The infant's cranium is huge relative to its face, and several bones are still not fused, see figure 1. Nine months after birth, the cranium is already half of its adult volume, since the rapid growth of the brain (Marieb 2004).

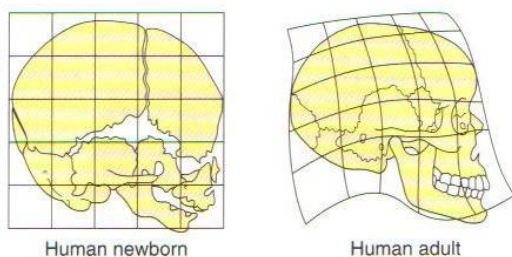


Figure 1. Differences between the cranium of a newborn and an adult (Marieb 2004).

2.3.1 Head

A major difference in anatomy between children and adults is the proportions of total mass in the head. At birth, the head comprises 20% of body weight while the adult head makes up only 6% of body weight. Most infants cannot hold up their heads until the age of about three months (Klinich et al. 1996).

Lengthwise, an infant's head is $\frac{1}{4}$ the total height, while an adult's head is $\frac{1}{7}$ the total height (Klinich et al. 1996). Figure 2 shows body proportions throughout life.

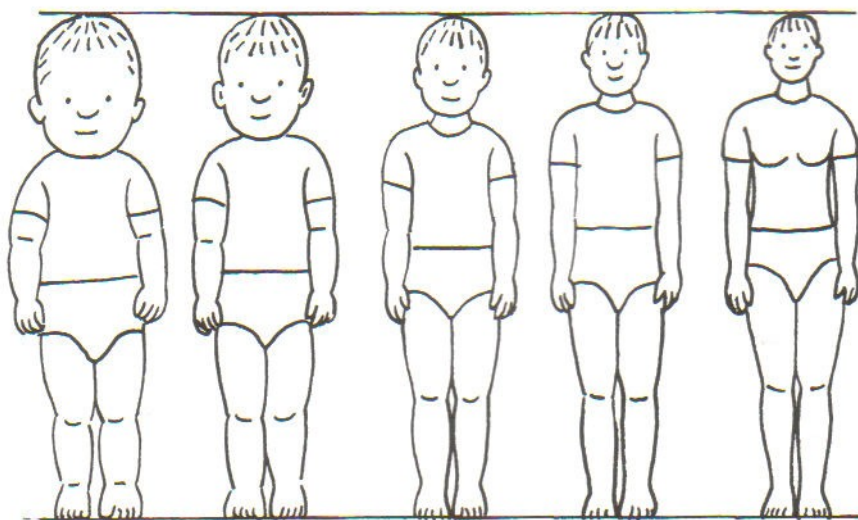


Figure 2. From left, the proportions of a newborn, 2-year-old, 6-year-old, 12-year-old and a 25-year old (Falkmer & Paulsson 2003)

The relatively large head may particularly affect neck loads, as a larger proportion of mass is being supported by a smaller structure. This may allow more neck injuries if not properly supported. The risk for whiplash injuries is therefore much bigger for a child than for an adult. Neck- and head injuries are more common by children than adults, while injuries on other parts of the body are more common by adults.

2.3.2 The vertebral column

The vertebral column or the spine in an adult is formed from 24 bones. They are distributed as follows

- Cervical vertebrae, 7 vertebrae in the neck (cervic=neck).
- Thoracic vertebrae, 12 vertebrae those lie posterior to the thoracic cavity.
- Lumbar vertebrae, 5 vertebrae that support the lower back (lumb = loin).

See figure 3.

Sacrum is a triangular bone formed by five sacral vertebrae. The sacral vertebrae begin to fuse in individuals between 16 and 18 years of age, the process is usually completed by age 30 (Tortora & Grabowski 2000). Coccyx is also triangular in shape and is formed by four vertebrae. The coccygeal vertebrae fuse when a person is between 20 and 30 years of age (Tortora & Grabowski 2000).

In the fetus and infant, the vertebral column consists of 33 separate bones. Nine of these form two composite bones, the sacrum and the coccyx. The remaining 24 bones build up the vertebrae, separated by intervertebral discs (Marieb 2004).

The newborn doesn't have the typical S-formed vertebrae, see figure 4. Only the thoracic and sacral curvatures are present at birth. The cervical and lumbar curvatures are associated with a child's development. The cervical curvature is pronounced when the baby starts to lift its head at about 3 months. The lumbar curvature develops when the baby begins to walk (Marieb 2004). All curves are fully developed by age of 10 (Tortora & Grabowski 2000).

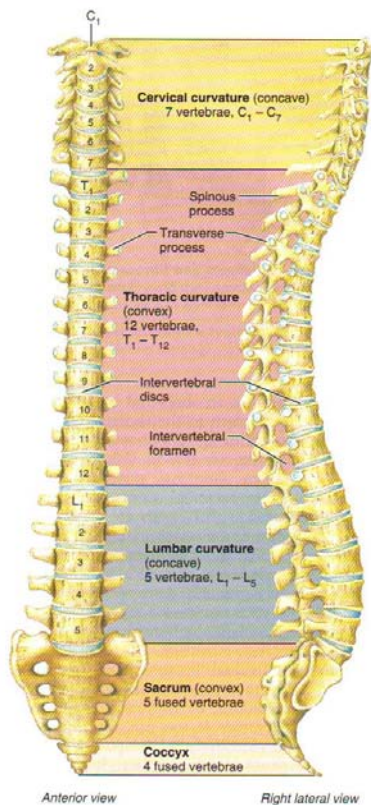


Figure 3. Vertebrae (Marieb 2004).

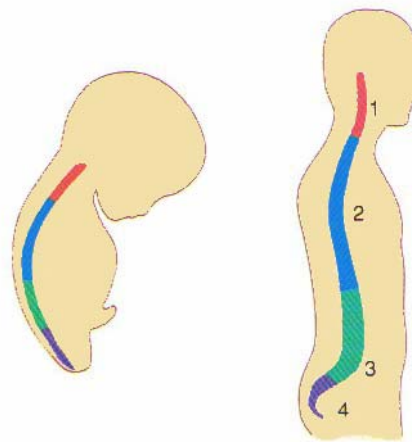


Figure 4. Single curve in fetus
Four curves in adult (Tortora & Grabowski 2000).

The neck vertebrae of children are immature models of the adult. These cervical vertebrae are mainly cartilaginous in the infant, complete replacement of this cartilage by bone occurs slowly (Huelke 1998).

The first and the second cervical vertebrae are not formed like the others. Typical cervical vertebrae (C3-C7) are formed from three primary bone formation centres, one in the anterior centre and two in the posterior neural arches. Between the neural arches and centre there is a cartilaginous junction called the neurocentral synchondrosis. Neural arches are connected to each other by posterior synchondrosis. At birth, the vertebral centres are oval and the height is equal to the height of the intervertebral disc. With advancing age, vertebral bodies become a more rectangular shape and their height increase, see figure 5 (Yogandan 1999).

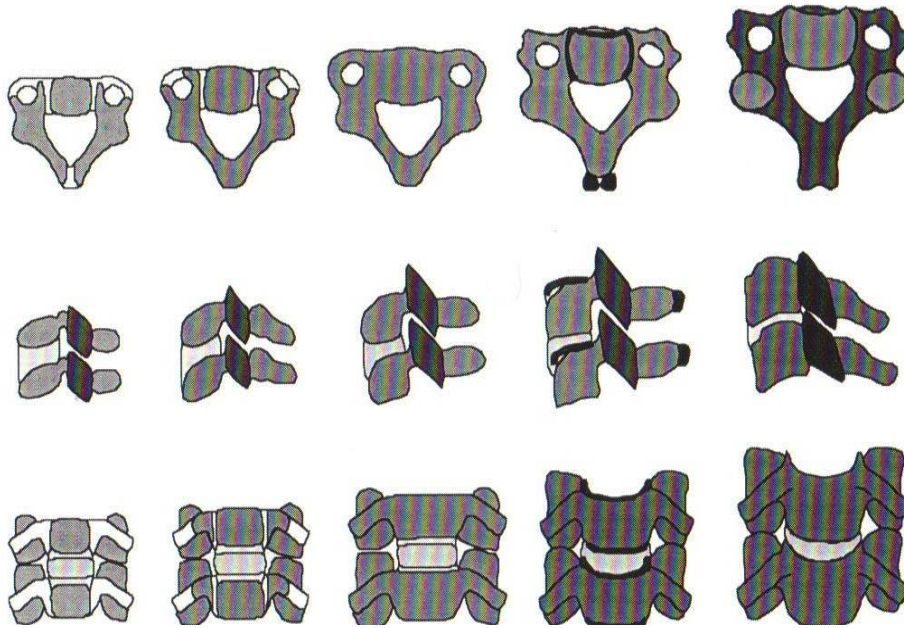


Figure 5. Cervical vertebrae. Top row shows from the top, middle row views functional units from the side and the bottom row from the front. The figures illustrate typical growth patterns. From left, patterns represent 0-12 months, 1-3 years, 3-6 years, 11-14 years and adult spines. Cartilages are shown in light background and bones in darker background.

(From Yogandan et al. 1999)

2.3.3 Other differences in Anatomy

The abdomen is different in that way that a smaller part is covered by the pelvis and rib cage (Tingvall 1987). The ribs by a child are more elastic and a force applied on the ribs will rather bend than break them. The force will be transferred to the inner organs (Anund et. al 2003).

There is also a difference between the child and the adult pelvis. The hip crest, or anterior superior iliac spine, which is important for the use of a lap belt, is not developed until the age of ten years (Tingvall 1987, Anund et. al 2003), see figure 6.

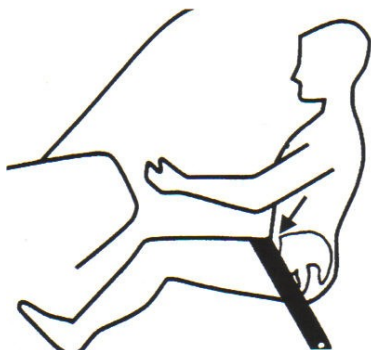


Figure 6. The hip crest (From Wevers 1983).

The differences in body segment proportions give a higher centre of gravity in the child, which may affect the body kinematics in the event of an accident (Anund et al. 2003A, Tingvall 1987).

2.4 Infant restraint systems

There are two main choices of child restraint system for newborn, rear-facing infant seats, figure 7, and car beds, figure 8.

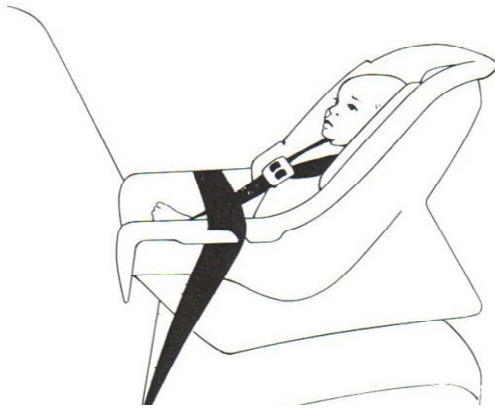


Figure 7. Rear-facing infant seat (Weber 1989)

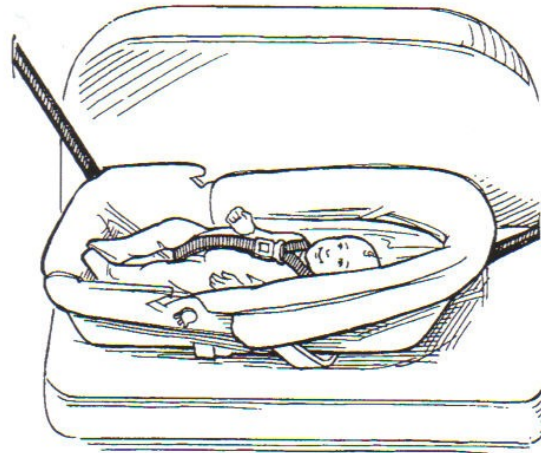


Figure 8. Car bed (American Academy of Pediatrics 1999)

2.4.1 Rear-facing infant seats

A rear-facing infant seat is suitable until the baby's weight is 10 kg or 13 kg. The infant seat can be placed in the passenger seat of the car or in the back seat of the car. If it is placed in the front seat it is important that there is no airbag fitted. Serious injury or death could occur if a rear-facing car safety seat is placed in front of an air bag and it inflates.

Another type of seat that sometimes is approved for use from newborn is one that faces rearwards that can be used until the child is around 15/25 kg. These are heavier than infant seats and will be left in the car. Young babies have to sit fairly upright in them. An infant safety seat is made to fit a little child; a rear facing child seat is made to fit a bigger child. The rear-facing child seat is mainly found in the Scandinavian countries (Isaksson-Hellman et al. 1997). In other European countries the children are placed forward facing earlier than in Scandinavian.

Examples of companies that manufacture rear-facing infant seats are AKTA, Britax, HTS and Maxi-Cosi. Some car manufacturers also manufacture their own infant seats. Infant seats, approved according to ECE R44/03, are labelled with an E.

2.4.2 Car beds and restrained Carry-cots

Car beds and restrained carrycots are restraint systems where the baby lies flat down. They will be placed in the rear seat, across the direction of the car and with the baby's head towards the vehicle's centre. These restraint systems are approved during to ECE R44 but crash tests have shown that it is not as safe as infant seats. Especially in systems without safety belts can a crash cause serious neck injuries. There is always a gap between the infant and the carrycot. In a crash the baby is thrown forward towards the front of the carrycot before the body stops.

This makes the load on the infant's body bigger than in a rear-facing seat. The Finnish company Akta has manufactured baby beds with safety belts inside, but because of low selling they do not manufacture them anymore.

2.4.3 Why rearward facing?

Crash tests on rear-facing child safety seats in frontal crash have shown that the seat back effectively reduces the crash force. The force is spread over a big area, the back, neck and head. Forward facing, the only thing that holds the child is the seat belt. By a crash the neck alone has to stop the rotation of the head, the forces on the neck are much bigger than by rearward facing (VTI).

The proportions of children with a relatively large head and undeveloped neck muscles, makes rear-facing child safety seats to be the safest way to place children in cars. Frontal crashes are far more frequent and more severe than rear end crashes. In Sweden the recommendation is to let children be placed rear-facing as long as possible, preferably until the child is 4 years old (Vägverket).

2.4.4 Attach system

The most common way to attach the infant safety seat to the car is with the seat belt, but different seats are differently restrained to the car; this causes difficulties leading to incorrect installation and non-usage.

Problems with correct installation of the child restraints to the vehicle structure have led to the development of a new attachment system. ISOFIX points are fixed connectors in a car's structure and an ISOFIX child seat can simply be plugged into them, see figure 9. The restraint system also has a supporting leg standing on the car floor to give stability. A benefit of ISOFIX is that it will create a rigid link between the child seat and the car to provide extra solidity. Many new vehicles have ISOFIX points built in when they are manufactured, and child seat manufacturers are beginning to produce ISOFIX child seats, which have been approved for use in specific car models, according to the Regulation ECE R 44/03. There is a suggestion for a change in the regulation so that CRS could pass a general ISOFIX approval, not just for specific car models.

The development of a new restraint system has been in progress since 1990. In 1993 Turbell et al. wrote a paper (ISOFIX – A new concept of installing child restraints in cars) about ISOFIX. They wrote that the installation of the child restraint systems in the cars is difficult, complicated and unstable. Highly desirable features with the new ISOFIX were to become an effective seat, simple to use and with an acceptable comfort for the child.



Figure 9. The main attachment is made by connecting the child seat to ISOFIX-bars in the car seat.
(Fair Srl)

3 Method

The work started with a literature search to find out more about long term health effects on infants in car seats and to identify mentioned risks with infant safety seats.

The search in the databases TRAX, TRIS, ITRD, SAE and Medline has been made by VTI Library and Information Centre, search terms are found in Appendices A1. A search on the World Wide Web was also included.

A general literature study was also made, to learn more about traffic safety, car seats, and children's anatomy. The general literature study gave a profound understanding for the topic.

Interviews with pediatricians, nurses and physiotherapists were made with the purpose to hear their opinions about risks with infant safety seats and their observations made on infants. The interviews consisted of a few basic questions, see Appendices A2, that were questioned to all persons, but for the rest the interviews were unstructured.

The selection of persons being interviewed was made under the work. The persons interviewed at the beginning gave advices who could know anything about the topic.

4 Results

Possible reasons why the time spent in infant seats would be limited are, according to the literature and people working with child safety:

- Difficulty to breathing
- Risk of Sudden infant death syndrome
- Crooked back
- Back injuries/not good for the back
- Delayed Motor development
- Vibrations

See Appendices A3 for details.

Almost all literature found, about effects on infants in car seats is about premature and low birth weight infants. Interesting is that no literature about back problems caused of infant seats was found.

The result from the interviews is presented with quotations from pediatricians and nurses.

4.1 Difficulty to breathing

The semi-upright position that the infant has in a car safety seat before it is able to sit upright by itself could cause difficulty to breathing.

Since 1990, the American Academy of Pediatrics¹ recommends that all infants who are born at <37 weeks' gestation be observed for respiratory instability and secure fit in their car seats before hospital discharge. Some studies have been made (Bass & Mehta 1995, Merchant et al 2001, Bass et. Al 2002) with both term and preterm infants and they shows that the Oxygen saturation declines during the time the infant sits in the car safety seat. In Sweden there is no recommendation about observations before hospital discharge and no Swedish or European research about difficulty to breathing in car safety seats were found.

4.1.1 Blood oxygenation

Bass & Mehta 1995 (Oxygen Desaturation of Selected Term Infants in Car Seats) monitored term infants for 90 minutes known to be at risk for O₂ desaturation or apnea. The 90-minute time is arbitrary but it does represent a reasonable time for a car trip. Eight of 28 monitored infants had a period of O₂ desaturation < 90%. Five of 28 monitored infants had borderline results, defined as O₂ saturation 90 to 93%. This study includes a highly selected population, all had problems identified before testing.

¹ The American Academy of Pediatrics is an organization of 57,000 primary care pediatricians, pediatric Medical subspecialists, and pediatric surgical specialists dedicated to the health, safety, and well-being of infants, children, adolescents, and young adults. AAP is the abbreviation for American Academy of Pediatrics. *PEDIATRICS* is the official journal of the American Academy of Pediatrics.

In year 2001 Merchant et al. made a study (Respiratory Instability of Term and Near-Term Healthy Newborn Infants in Car Safety Seats) with term and near-term healthy newborn infants. Fifty healthy preterm infants and 50 term infants in Minnesota, USA were studied. Heart rate, Respiratory rate and Pulse oximetry were evaluated while infants were supine and in their car safety seats. 24% of the preterm and 4% of the term newborns did not fit securely into the car safety seats despite the use of blanket rolls for positioning infants. Mean Oxygen saturation values declined significantly in both preterm and term infants from 97% in supine position to 94% after 60 minutes in their car safety seats. In the discussion of this report Merchant et al. say:

Although car seats often are used as carriers for newborn infants, our data indicate that preterm and term newborns should not remain in car seats for extended periods of time when they are not travelling. The American Academy of Pediatrics recommends that travel be minimized for premature infants, and our data suggest that full-term newborns also would benefit from this recommendation.

Bass et al. wrote 2002 (Oxygen desaturation in term infants in car seats) that there is a need for observations of infants born prematurely in car safety seats. They are at risk for Oxygen desaturation and Apnea. If healthy term infants are at risk for similar episodes in car safety seats warrant additional investigation.

4.1.2 Comments from Swedish Physiotherapists

It is important to keep in mind that O₂ desaturation may occur even when supine. Physiotherapists sometimes recommend placing infants with difficulty to breathing semi-upright with satisfactory support for the back to facilitate the breathing.

4.1.3 Head flexion

It is a common observation, from parents and from clinics, that premature infants and also some full-term infants are falling asleep with their head to chest in infant seats (Tonkin et al. 2003). This head flexion can lead to upper airway narrowing.

A study from Tonkin et. al 2003 (Simple Car Seat to Prevent Upper Airway Narrowing in Preterm Infants: A pilot study) strongly supports the hypothesis that flexion of the head on the body is a significant contributor to episodes of oxygen desaturation. The study also shows that an insert in the car seat effectively reduces the episodes of oxygen desaturation. Many infant safety seats have an insert to improve the head position for small babies.

4.2 Sudden infant death syndrome (SIDS)

SIDS is the sudden death of an infant under one year of age which remains unexplained after a thorough case investigation, including performance of a complete autopsy, examination of the death scene, and review of the clinical history (Willinger et. al 1991).

Infant safety seats have been mentioned as a risk factor for SIDS. When the infant safety seats became popular, the cases of SIDS increased.

In Norvenius' dissertation from 1997, Sudden infant death syndrome in Sweden in 1973-1977 and 1979 is reported that some cases of SIDS had occurred in cars. All cases were lying in a baby-carrier, which hindered their moving.

In Alm's dissertation from 1999, Sudden infant death syndrome in Scandinavia: an epidemiological study is reported that 4 from 244 cases died of SIDS during a car ride, none of them in a rear facing infant seat. All cases were lying in a baby-carrier.

In the comparison of Norvenius' study from the period 1973-1977 and 1979, with the Swedish part of the Nordic Epidemiological SIDS Study 1992-1995, the deaths in cars decreased from 10 % to 2 %.

Bernt Alm, MD, PhD, at the Queen Silvia Children's Hospital does not think that rear facing infant seats increase the risk of SIDS, rather that they decrease the risk. Blocked emitting of heat from the face and rebreathing of carbon dioxide could be contributory causes to SIDS. In a rear facing infant seat the baby's face is freer than in a baby-carrier.

4.3 The back

The most common reason mentioned in Sweden and Europe why the time spent in infant seats would be limited is that it could hurt the infant's back, if it is placed upright before the infant is able to sit upright. In the USA the situation seems to be different. Joel Bass has made a research about difficulties of breathing (Oxygen desaturation in term infants in car seats) in infant safety seats, but he has never heard about back problems in connection with infant safety seats.

No research on effects on infant's backs in infant seats was found. No one of the contacted Swedish and European pediatricians, orthopedists, physiotherapists, nurses, infant seat manufacturer or people working with traffic safety research was aware of any made scientific research.

In child safety information from Denmark, a recommendation for how long infants can sit in infant safety seats were found, not more than 20-30 minutes the first two months (Rådet for Større Færdselssikkerhed). The recommendation comes from the senior pediatrician Birgit Peitersen but there is no scientific result supporting this statement.

4.3.1 Comments from Pediatricians

Staffan Jansson, professor at Karlstad University, Sweden and pediatrician, has worked with child safety. He says:

This question was of current interest already in the beginning of the 80s when we started to lent out child safety seats on maternity wards. Our opinion at that time was (and is still) that parents shall be requested to be watchful on their child, if it seems to feel bad when it is sitting in the child safety seat. You usually recognise that the child slouch and shows sign of discomfort and may starts to

cry. For all I know have this recommendations worked out well (also when it comes to baby bouncers). That the child safety seats would injure children's backs is a worry that is understandable, but it has no cause. In contrast to adults infants inform if they feel bad. The problem is not the children, but the parents that don't react to these signals.

During the years, I have never seen any authoritative article that connects injuries or changes in children's backs to long terms in child safety seats or baby bouncers. Scoliosis is an inborn affection. If Scoliosis should appear because of load injuries they have to be extreme and long (as child labour in developing countries)

Birgit Peitersen, senior pediatrician on the ward for children on Hvidovre Hospital in Denmark, recommend that the time spend in infant seats are limited the first months. The reason she gives is that the neck muscles are too weak to hold up the heavy head.

An infants head is heavy and the strenth of the neck muscles rather weak, and therefore the child have to be trained before it is adviseable to let the baby sit upright for more than 20-30 minutes at a time.

She has discussed this problem with child neurologists, child physiotherapists and others involved in infant car safety and in children's development and they have come to an agreement that 20-30 minutes is a convenient recommendation for the first two months.

4.4 The use of infant safety seats outside the car

The design of infant safety seats tempts the parents to use them also outside the car. They have a handle so parents can carry their baby in them and they can be used as rocking chair, some models can be clipped onto a pushchair.

In information from Austria the recommendation is to only travel in car with infants if it is absolutely necessary. According to this information from "Österreichischen Bundesministeriums für Verkehr, Innovation und Technologie" can the crooked position the infant has in the car seat affect the infant's healthy development. They give this recommendation to reduce the use of infant safety seats outside the car, but are not aware of any scientific results showing that the development is affected.

4.5 Motor development

Also the motor development has been mentioned to be affected of too much use of infant safety seats. Similarities can be seen to baby bouncers.

In a baby bouncer the baby is placed in a similar position as in an infant safety seat. There are recommendations for how long a baby can be placed in a baby bouncer too. Some pediatricians do not recommend that the baby is placed in a bouncer chair at all the first two months because the neck is not strong enough to hold up the baby's head, and it can hurt the baby's back. Another reason heard why the time should be limited is that a baby need to lie down on the floor where they can move free and train their muscles. Sometimes infant safety seats are used at home as a baby bouncer.

There are no scientific studies found, showing that too much use can hurt the baby's back. But pediatricians do not recommend that parents placed their babies in bouncer chairs for hours every day. The most common reason is that at home it is necessary for the baby to lie on the floor and practise to do motor development.

Per Möllborg, Swedish Pediatrician

Spontaneous, I do not think that too much time spent in a baby-bouncer is good and it can affect the motor development negatively in a short perspective. But the motor development lies "programmed" in us and I think that some use, short moments, does not affect the development at all.

One big difference between an infant safety seat and a baby bouncer is that an infant safety seat is used to protect infants from injury and death.

Anne-Berit Ekström, Chief Physician in Child Neurology

It is important to encourage parents to let their child have many different positions; it is good to let the child lie flat on one's face when awake and at home – this stimulate the motor development. In the car it is obviously that the child shall have a secure car seat. It is absolutely right with frequently occurring breaks. Breaks once an hour would do both children and driver good.

Also physiotherapists mentioned motor development as reason for why the time spent in infant safety seats should be limited.

4.6 Vibrations

A study made of Giacomini (Some observations regarding the vibrational environment in child safety seats, 2000) showed that the vibration levels measured at the interface between the children and their seats were found to be higher than the vibration levels between the driver and the driver's seat. Vibration is both a source of discomfort and a possible risk to human health (Giacomini 2000).

5 Transportation of children with special needs

There are no medical reasons that mean that it is allowed to transport children unprotected. Crash tests on dummies representing children with special medical needs in any restraint system have not been studied (American Academy of Pediatrics 1999). Children with special needs can have different body proportions than normal children (Falkmer & Paulsson 2003).

A child with special health care needs may require frequent observation during travel. If no adult is available to accompany the child in the back seat, the front seat is to be considered (Falkmer & Paulsson 2003).

5.1 Dislocated hip

By 1-2 of 1000 newborn is the hip unstable and dislocated (Nationalencyklopedin). Developmental dysplasia of the hip (DDH) describes a variety of conditions in which the ball and socket of the hip do not develop properly, se figure 10.

If the condition is detected around the time of birth, a lightweight splint that holds the legs apart (abducted) may be applied. This position aids the correct growth of the ball and socket joint. The splint is worn for several weeks and is only removed at the clinic.

This splint can cause difficulties to place the infant correct in an infant safety seat, but at Karolinska University Hospital in Stockholm all infants treated for dislocated hips travel in an infant safety seat.

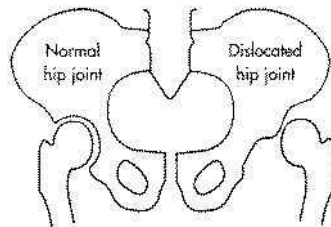


Figure 10. A normal and a dislocated hip joint (Steps Association for People with Lower Limb Abnormalities).

5.2 Car seat safety for preterm infants

Positional problems of premature infants in car seats were first reported in by Bull & Bruner Stroup in 1995. These small infants do not always fit securely in standard infant car safety seats (Merchant et al. 2001). As mentioned in chapter 4.1 Respiratory instability in the upright position is a particular problem for premature infants. Premature infants who are discharged from intensive care nurseries are known to be in increased risk for Apnea, Bradycardia and oxygen desaturation while in upright position.

Bull & Bruner Stroup, wrote 1985 about the efficiency of infant safety seats.

Although the very small infant may not fit perfectly into a car safety seat, it is imperative for health care professionals to emphasize that it is always safer for the baby to travel correctly restrained in an approved safety seat than in an infant carrier or a parent's arm

Part 2

6 Vibration

Vibrational comfort is important in child safety seats. Children are more and more becoming regular passengers in vehicles and researches have shown that vibration is both a source of discomfort and a possible risk to human health (Giacomin 2000).

6.1 What is Vibration?

Vibration is oscillatory motion. By definition, the motion is not constant but alternately greater and less than some average value (Griffin 1990). Oscillatory motions can be simple (sinusoidal), or complex but it can also be random and irregular.

Acceleration is often used to state the power of the vibration or the level of the vibration, because the acceleration is the unit that best describes the effects of vibrations on humans (Arbetslivsinstitutet). Translational acceleration is expressed in meters per second squared [m/s^2] and rotational acceleration in radians per second squared [rad/s^2] (ISO 2631-1, 1997).

The acceleration magnitude of a vibration could be expressed in terms of the peak-to-peak acceleration or the peak acceleration. By complex motions it is often preferred to describe the motion with the effective value, also called r.m.s value, root-mean-square value (Arbetslivsinstitutet). The r.m.s value of the acceleration $a_{r.m.s}$, is defined as

$$a_{r.m.s} = \sqrt{\frac{1}{T} \int_0^t (a(t))^2 dt}$$

where $a(t)$ is the acceleration value at the time t and T is the total time for which the r.m.s value is calculated.

Since a sinusoidal motion is symmetric the r.m.s value is the peak value multiplied by 0.707. See figure 11.

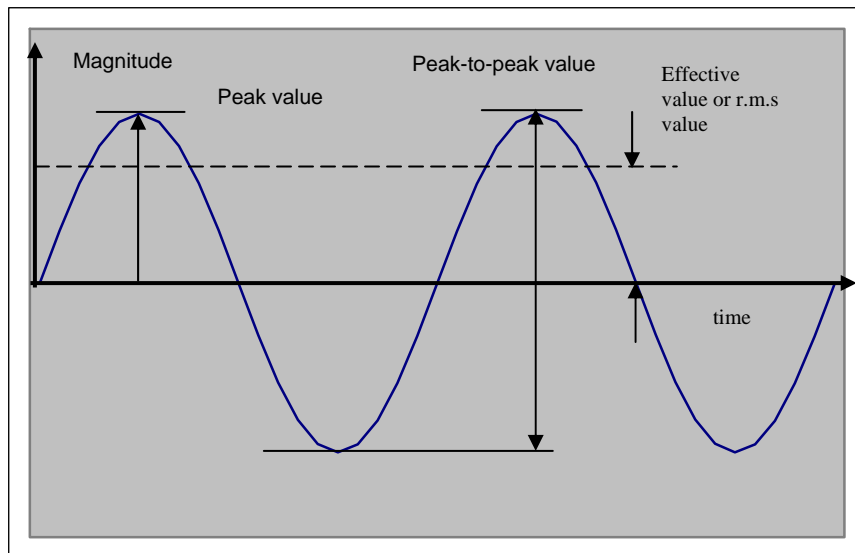


Figure 11. Peak, peak-to-peak and r.m.s value for a sinusoidal motion.

6.2 Whole-body vibration

Whole-body vibration occurs when the body is supported on a surface, which is vibrating, for example when sitting on a vibrating car seat. The dominant vibration transmitted through the seats of vehicles is often at frequencies below 20 Hz (Griffin 1990). Humans are sensitive for whole-body vibration from 0.05 Hz to 100 Hz (Giacomin 1997), but a constant magnitude does not produce the same discomfort at all vibration frequencies (Griffin 2000). At frequencies below 1 or 2 Hz forces acting on the body are approximately proportional to the input acceleration and the same movement is transmitted throughout the whole body. At higher frequencies body resonance tend to amplify the motion and overall discomfort depends on sensations in different parts of the body (Griffin 2000).

For vertical vibration, the motion is perceived most easily at 1-16 Hz and most easily at about 5 Hz (Mansfield 2005).

Strong vibration stress that leads to resonance vibration of the organ systems can cause physiological reactions on the basis of high mechanical stress on body tissue alone (Dupuis & Zerlett 1986). The reactions in the body depends on

- Vibration frequency
- Vibration intensity
- Exposure time
- Body position (laying, sitting or standing)
- The direction of the vibration

(Lidström & Hansson 1976)

Physiological reactions to mechanical vibration can be but are not necessarily perceived by the people who are exposed. At first, the reactions are acute and therefore can sometimes be measured. Sometimes they are not immediately noticeable at the beginning of the mechanical stress but are perceived after 1 or 2 hours, such as motion sickness. They are caused mostly by very low-frequency vibration with great displacement amplitude, but are also influenced by additional factors. These illnesses are of an acute nature and do not always begin

immediately after the onset of stress, but often after a longer period of exposure (Dupuis & Zerlett 1986). Infants under the age of 18 months, however, have been found to be largely immune to motion sickness (ISO 2631-3 1985).

It should not be implied that in principle mechanical vibration only has negative effects on the human body. There are also positive effects; vibration stress can cause the relaxation of certain tense conditions. In order not to achieve the opposite of what is being sought, the acceleration initiated must lie in a frequency range in which the human body is relatively insensitive. Its amplitude must not be too high and the effective time must be kept short. One must take into account that when the exposure time is longer, a condition of monotony will be reached, which will lead to adaptation and result in reduced activity and fatigue (Dupuis & Zerlett 1986).

By exposure of vibrations with low intensity is fatigue the dominating symptom (Lidström & Hansson 1976).

6.3 Vibration measurement

The international standard ISO 2631 is a guide for the evaluation of human exposure to whole-body vibration. It also defines an orthogonal co-ordinate system for the expression of the magnitudes of vibration occurring in different directions, see figure 12.

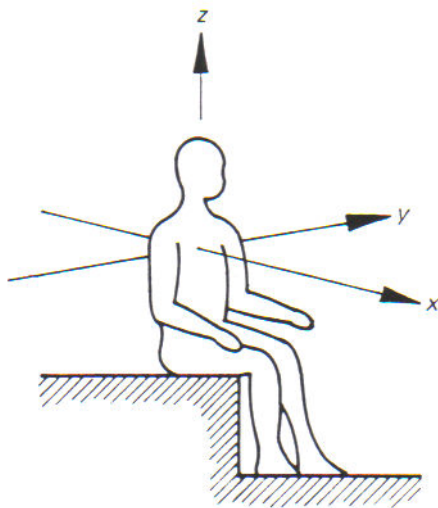


Figure 12. Co-ordinate system for vibration measurements on seated person, defined in ISO 2631-1

ISO 2631-1 from 1997 which has been used in this work covers vibration in the frequency range from 1 Hz to 80 Hz. The standard requires that vibration magnitudes should normally be expressed in frequency weighted m/s^2 root-mean-square (r.m.s). Transfer functions for frequency weighting filters are defined in Annex A in the standard.

When the magnitude of vibration increases, there is usually an increase also in discomfort (Griffin 1990).

Human sensitivity to vibrations expressed in their r.m.s value according to ISO 2631-1 is found in table 2.

Table 2. Humans sensitivity to vibration, according to ISO 2631-1

Weighted r.m.s value	Human sensitivity
Less than 0.315 m/s ²	not uncomfortable
0.315 m/s ² to 0.63 m/s ²	a little uncomfortable
0.5 m/s ² to 1 m/s ²	fairly uncomfortable
1.25 m/s ² to 2.5 m/s ²	very uncomfortable
Greater than 2 m/s ²	extremely uncomfortable

There is no linear correlation between the r.m.s value and the discomfort. The relation between the sensation magnitude and the stimulus intensity are described by Steven's power law²

When a vibration contains occasional bumps the discomfort it produces may not be well predicted by the r.m.s value. The crest factor describes the quotient between the peak value and the effective value of the acceleration.

$$\text{Crest factor} = \frac{a_{peak}}{a_{r.m.s}}$$

Typical vibration in a vehicle on a good road may have a crest factor in the range 3-6 (Griffin 1990). When the crest factor is above 9, it is not possible to evaluate human response to vibration using the frequency-weighted r.m.s acceleration (ISO 2631-1 1997). The standard contains supplement values to calculate when the crest factor is above 9, but there are no methods for evaluating their influence on comfort.

6.4 Vibrations in vehicles

The size of the vibrations transferred to the passengers through the vehicle depends on the road surface and the velocity. Furthermore the mechanical quality of the vehicle has influence. The car body has an eigenfrequency for vertical vibrations at about 1 Hz, which means that this frequency is amplified with a factor 1.5-3.0. The axles of a car have an eigenfrequency at 10-15 Hz (Granlund 2000). Automobile seats often have a resonance frequency at 4-5 Hz. That coincides with the frequency where the vibrations are most easily perceived (Mansfield 2005).

² Steven's power law, $S=kI^a$, where S is sensation magnitude, k and a are constants and I stimulus intensity.

6.5 Vibrations in infant safety seats

In two previous vibration studies of child safety seats fastened with the seat belt (Giacomin, 2000, Giacomin 2003), the belt-fastened child seats were found to be less effective than the automobile seats in attenuating vibrations. In both these previous studies is mentioned that attachment systems such as ISOFIX (see Chapter 2.4.4 for more information about ISOFIX) would be expected to result in different vibration characteristics, because of the rigid connection between the child safety seat and the car body.

7 Method

To find out more about the vibrational environment in different types of infant safety seats, field acceleration measurements were made. The vibration experiment consisted of measurements in infant safety seats during runs over different road surfaces.

7.1 Child safety seats

Three different types of child safety seats for infants were tested in this study, see figure 13.

- Infant safety seat attached with ISOFIX from Fair Srl
- Infant safety seat with a base fasten with the seat belt and the seat attached in the base from AKTA Graco
- Infant safety seat traditionally fastened with the seat belt from Maxi-Cosi.

See more information about the different seats in table 3.



Figure 13. Tested child safety seats. From left: Bimbofix from ISOFIX, Autobaby from AKTA Graco and Cabrio from Maxi-Cosi

Table 3. Tested infant safety seats

	Bimbo Fix	Autobaby	Cabrio
Manufacturer	Fair Srl	AKTA Graco	Maxi-Cosi
Group	0-1	0+	0+
Supporting leg	yes	yes	no
Fastened with seat belt	no	yes, the base	yes

The infant safety seats were installed in the back seat according to product instructions. A 9-kg child dummy was placed in the different child safety seats during the rides, see figure 14.



Figure 14. Dummy placed in infant safety seat with base from AKTA Graco

7.2 Points of measurement

Translational acceleration was measured with accelerometers. The accelerometers measure the accelerations in m/s^2 . For performing acceleration measurements in the child seat, no standard devices were available. The measurements were, therefore, made with an accelerometer fastened in the child dummy, see figure 15 and 16. The accelerometer follows the motions of the dummy.



Figure 15. Accelerometer fastened in dummy



Figure 16. Accelerometer

Two more points for measurements were chosen, the interface between the driver's seat and the driver and the floor.

The measurements in the driver's seat were made with a seat pad containing accelerometers, see figure 17. This type of semi-rigid pad is used for vibration measurements on a seat, and is defined in ISO Standard, ISO 10326-1.

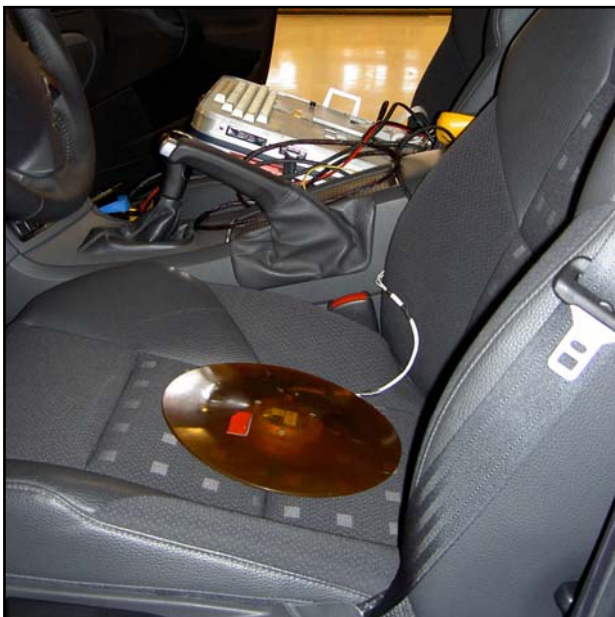


Figure 17. Seat pad for vibration measurements in driver's seat.

The accelerometer on the floor was mounted on a seat guide using double-sided adhesive tape, see figure 18. Ideally, measurements should be made at many points on the floor.

However, it can be assumed that the floor is rigid and that roll and pitch vibrations are negligible. Then a mounting point on one seat guide will suffice (Mansfield 2005). It is important that the accelerometer on the floor is thoroughly fixed; it must be rigid in the frequency range of interest.



Figure 18. Accelerometer on the seat guide on the floor.

7.3 Cars

Tests were performed in two different cars. A Volvo V70 model 2004 and an Opel Vectra model 2003. Both cars had efficient tyres.

7.4 Road surfaces

The selected road surfaces were gravelled road, country road and a speed bump, figure 19-21.



Figure 19. Country road



Figure 20. Gravelled road



Figure 21. Speed bump

A vibration measurement should, if possible, last at least 3 minutes, for ensure reliable measurements. And at least 3 repeat measures should be taken (Mansfield 2005).

The measure over a speed bump cannot last 3 minutes, it is a transient vibration, but the other measurements last 3 minutes and 3 repeat measures were taken.

7.5 Measurement equipment

All accelerometers used, are assembled at VTI for former vibration measurements in cars. The same type of accelerometer was used for the measurements on the floor and in the child safety

seats. The 3 accelerometer components inside measuring the accelerations in the x-, y- and z-axis come from VTI Technologies (before 2002 VTI Hamlin) and are of the model SCA600. The seat pad used for measurements in the driver's seat has three accelerometers from Entran Devices Inc. model EGC-500DS.

The acceleration time histories were sampled at a rate of 250 Hz. All signals were amplified and passed through a low-pass filter having a cut-off frequency of 100 Hz, before acquired, to avoid aliasing³. Data were acquired with a laptop and a DAQCard-700 from National Instruments.

The speed was controlled using the vehicle's instrumentation and when possible the car's cruise control. The velocity was 50 km/h on the country road and 30 km/h on the gravelled road and over the speed bump.

7.6 Data analysis

The signal processing is shown in figure 22. As mentioned in chapter 7.5 Measurement equipment, all signals were amplified and passed through a low-pass filter before acquired. In MATLAB the signals passed through a low-pass filter in order to maximize the signal-to-noise ratio.

If the purpose is to estimate the vibrations influence of people, measured accelerations have to pass through frequency weighting filters, defined in Annex A in the international standard ISO 2631-1. These filters have been implemented in MATLAB as digital filters.

The frequency-weighted signals were plotted and important values according to ISO 2631-1 were calculated in MATLAB. Spectral analysis is carried out on unweighted signals. According to Mansfield (2004), that is the usual way to do it. Before the spectral analysis the data passed through a high-pass filter with a cut off frequency of 0.4 to eliminate the DC-component.

³ Aliasing occurs when a sampled signal contains energy at frequencies greater than half the sampling frequency. Any higher frequency components are folded back to frequencies below half the sampling frequency.

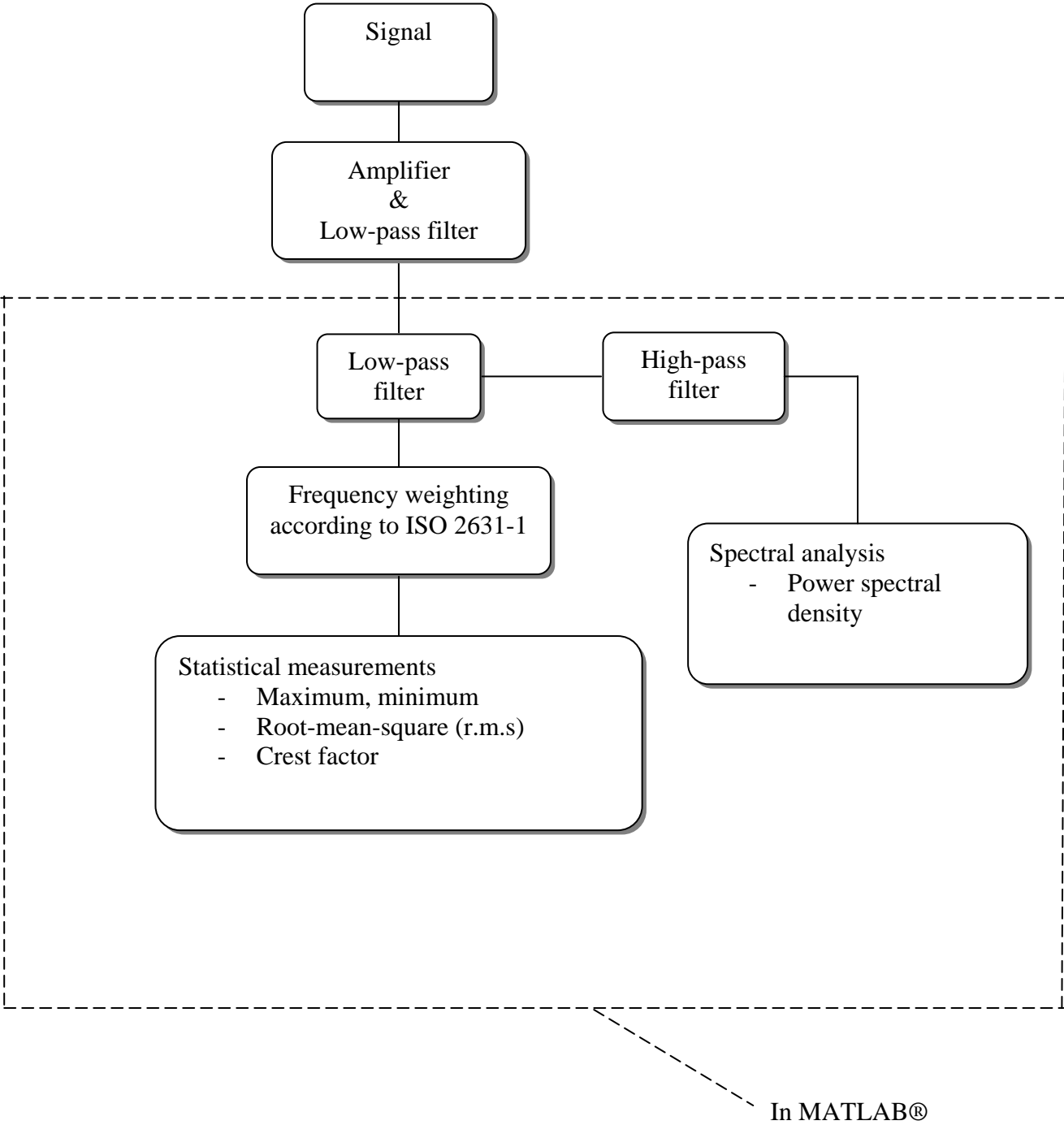


Figure 22. The signal processing

8 Results

Data from the measurements have been analysed with statistical measures of the frequency-weighted accelerations and with spectral analysis.

8.1 Analysis in time domain

Vibrations were measured in x-, y- and z-axis, but analysis of the data showed that the vibrations in x- and y-axis were rather small in relation to the vibrations in z direction. Therefore the results in vertical direction, in z, are presented here and the results in x and y are presented in tables in Appendices A5.

Figure 23 shows the vibrations from one minute on country road from the Volvo and figure 24 shows the vibrations from one minute on country road from the Opel. It can be seen that the vibrations reaching the dummy in the three different infant safety seats have higher amplitude than the vibrations reaching the driver. It can also be seen in figure 23 that the vibrations on the floor have hardly higher amplitude than the vibrations in the driver's seat. That is a trend in all data from the measurements in the Volvo. It makes sense to think that the amplitude should be higher at the floor, which is a part of the car body. The automobile seats have cushion to attenuate vibrations coming from the road through the car body. The accelerometer fastened on the seat guide with double-sided adhesive tape has probably not been correctly fastened. The data from the measurements performed in the Opel, see figure 24, shows that the accelerometer on the floor were better fastened in this car, but the levels on the accelerations are not that much higher then the levels in the driver's seat. The infant safety seat attached with ISOFIX has higher amplitude then the other two infant safety seats. The seat with a base and the seat fastened with the seat belt have similar amplitudes.

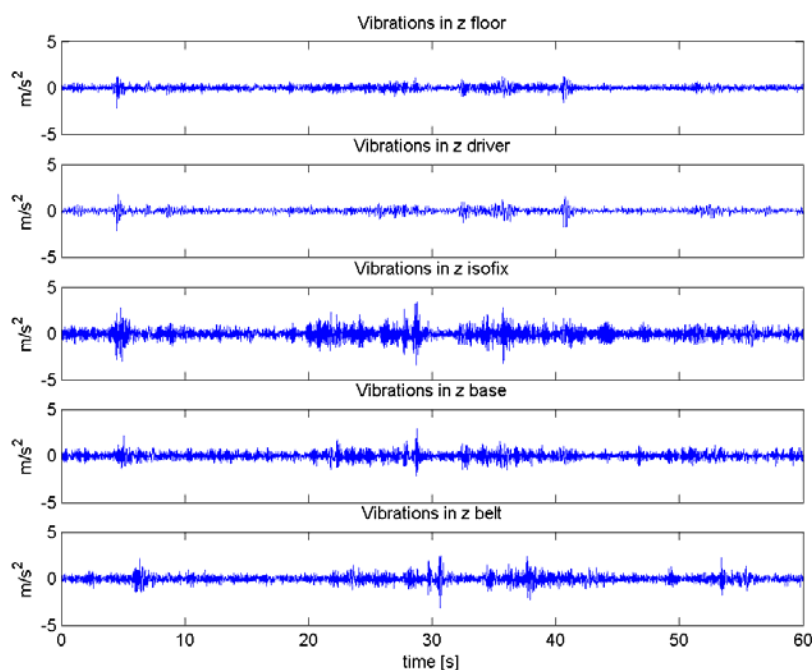


Figure 23. Acceleration time history from one test with the Volvo on country road 50 km/h.

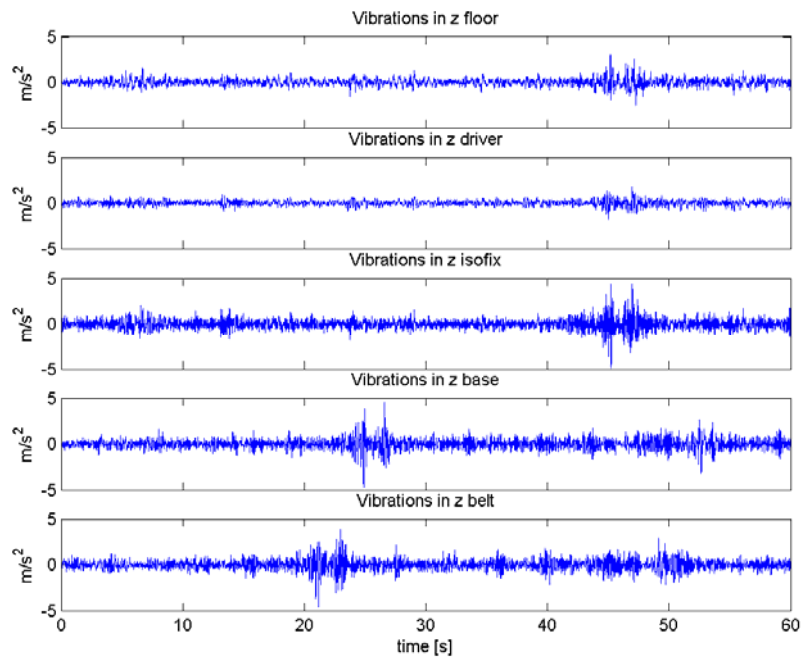


Figure 24. Acceleration time history from one test with the Opel on country road 50 km/h.

Table 4-6 shows that the mean minimum value from all tests was smallest for the ISOFIX seat and the mean maximum value and mean r.m.s accelerations from all tests were highest for the ISOFIX seat in both cars. Some of the measurements contained an extremely high maximum value coming from an occasional bump. When it only occurred once during the three minute measure period this part of the signal were thrown away and an r.m.s value for the rest of the signal were calculated. Figure 25 shows the r.m.s accelerations for the infant seats on gravelled road from all tests performed with the Volvo and figure 26 shows the r.m.s accelerations for all tests with the Opel. It can be seen that the values from the infant seat fasten with ISOFIX are much higher in the Volvo and high in the Opel. It is a trend from all tests that the amplitude of the vibrations measured in the infant seat fastened with ISOFIX are high in proportion to the other infant seats.

Table 4. Summary of the frequency weighted vibration signals in z direction measured on country road at 50 km/h. Values are in m/s^2

	Volvo				Opel			
	Min Value	Max value	r.m.s value	Crest factor	Min value	Max value	r.m.s value	Crest factor
Driver	-2.130	1.964	0.266	8.856	-2.161	2.200	0.312	7.051
Floor	-2.217	1.819	0.258	7.044	-3.145	3.376	0.424	8.135
ISOFIX	-3.521	4.086	0.511	7.945	-4.621	4,110	0.526	7.868
base seat	-2.550	2.831	0.401	7.059	-4.160	4.037	0.516	7.808
belt seat	-3.263	2.929	0.406	7.208	-3.915	4.054	0.500	8.107

Table 5. Summary of the frequency weighted vibration signals in z direction measured on gravelled road at 30 km/h. Values are in m/s^2

	Volvo				Opel			
	Min Value	Max value	r.m.s value	Crest factor	Min value	Max value	r.m.s value	Crest factor
Driver	-3.415	3.622	0.765	4.731	-4.332	4.198	0.704	5.990
Floor	-4.233	4.228	0.851	4.963	-5.528	6.058	0.963	6.359
ISOFIX	-6.883	8.756	1.701	5.485	-8.713	11.313	1.775	6.376
base seat	-4.814	5.256	1.243	4.229	-7.605	11.055	1.574	7.058
belt seat	-5.575	5.773	1.301	4.446	-8.077	10.253	1.716	5.984

Table 6. Summary of the frequency weighted vibration signals in z direction measured on speed bump at 30 km/h. Values are in m/s^2

	Volvo				Opel			
	Min Value	Max value	r.m.s value	Crest factor	Min value	Max value	r.m.s value	Crest factor
Driver	-2.798	2.733	0.521	5.266	-2.480	2.731	0.661	4.117
Floor	-3.660	3.565	0.658	5.700	-3.444	4.624	0.931	4.959
ISOFIX	-3.659	4.351	0.747	5.871	-5.778	8.771	1.431	6.124
base seat	-3.312	3.458	0.738	4.674	-4.184	5.726	0.990	5.839
belt seat	-3.375	3.563	0.687	5.360	-4.726	7.832	1.044	7.504

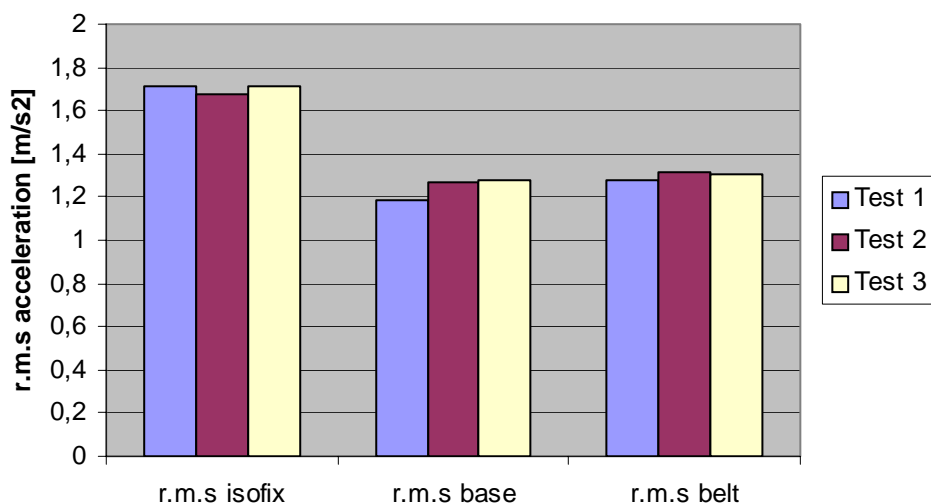


Figure 25. The r.m.s accelerations for the infant safety seats in the Volvo on gravelled road.

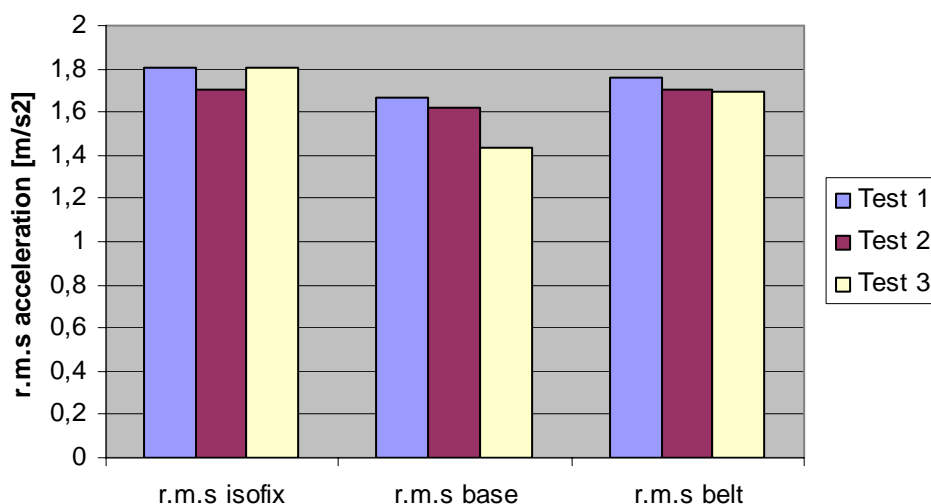


Figure 26. The r.m.s accelerations for the infant safety seats in the Opel on gravelled road.

8.2 Spectral analysis

Fourier analysis was performed and the results in the frequency domain are presented by Power spectral density [m^2/s^3].

Figure 27 and figure 28 present two examples of acceleration Power spectral density obtained in the different infant safety seats and in the driver's seat in vertical direction during a test on country road in 50 km/h. It is not that easy to find a pattern in the Power spectral density for the different tests, but a few tendencies can be found.

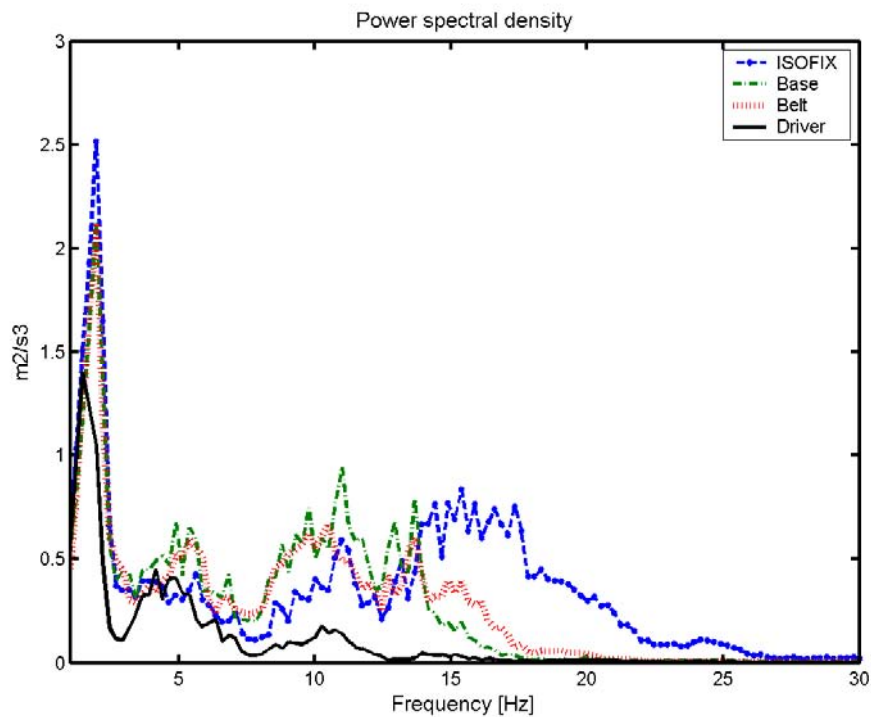


Figure 27. Power spectral density during a test run on country road in the Opel at 50 km/h

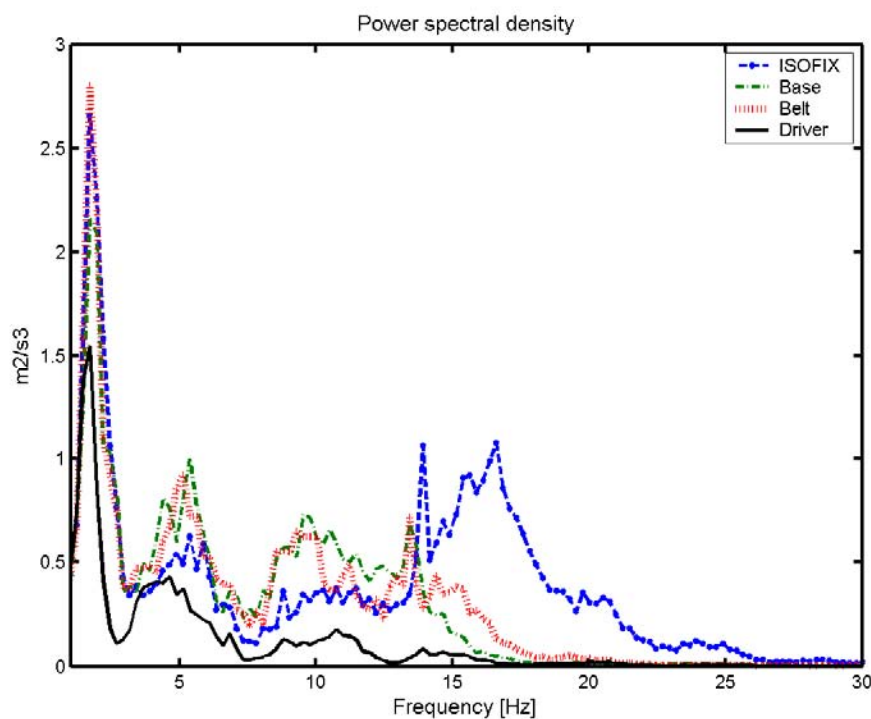


Figure 28. Power spectral density during another test run on country road in the Opel at 50 km/h

The two different seats fastened with the seat belt have rather similar energy. The ISOFIX seat has in general lower energy than the other two seats for frequencies between 1 and 15 Hz,

but much higher energy in the region 15-25 Hz than the other two infant seats. The seat fastened with the belt and the seat with the base have hardly no energy for frequencies over 20 Hz. All infant seats have a peak at about 5 Hz where the motion is most easily perceived. Figure 29 and figure 30 present the mean of the three tests for each infant safety seat and car on country road.

On gravelled road almost all frequencies up to 15 Hz are presented with high energy in the Power spectral density, and the measurements from the three infant seats have all higher energy than the measurement in the driver's seat.

Because of the uncertain measure on the floor in the Volvo, the transmissibility⁴ from the floor to the infant seats and driver has only been calculated for measurements in the Opel. R.m.s values for the floor and driver's seat from all tests on Country road are found in Appendices A4. The mean transmissibility for the three different types of infant safety seats is presented in figure 31. It is evident that the ISOFIX seat has a higher transmissibility for frequencies over 15 Hz than the other two seats, but a lower transmissibility for lower frequencies.

⁴ Transmissibility is ratio of the accelerations measured at the investigated surface and at the reference point. Transmissibility values greater than 1 indicate that the interface amplifies the vibration. Values lower than 1 indicate that the interface attenuates the vibration.

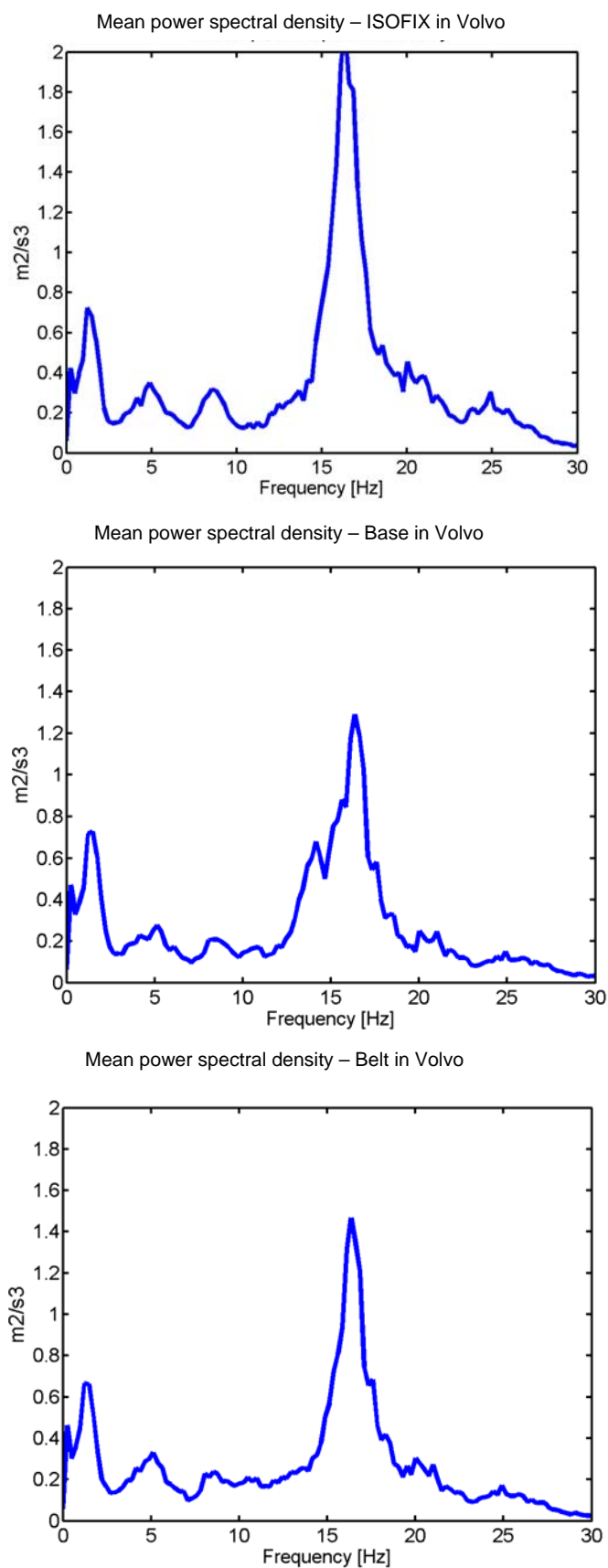


Figure 29. Mean power spectral density of the three tests for each infant safety seat in the Volvo, upper ISOFIX, in the middle the seat with base and under the seat fastened with the belt

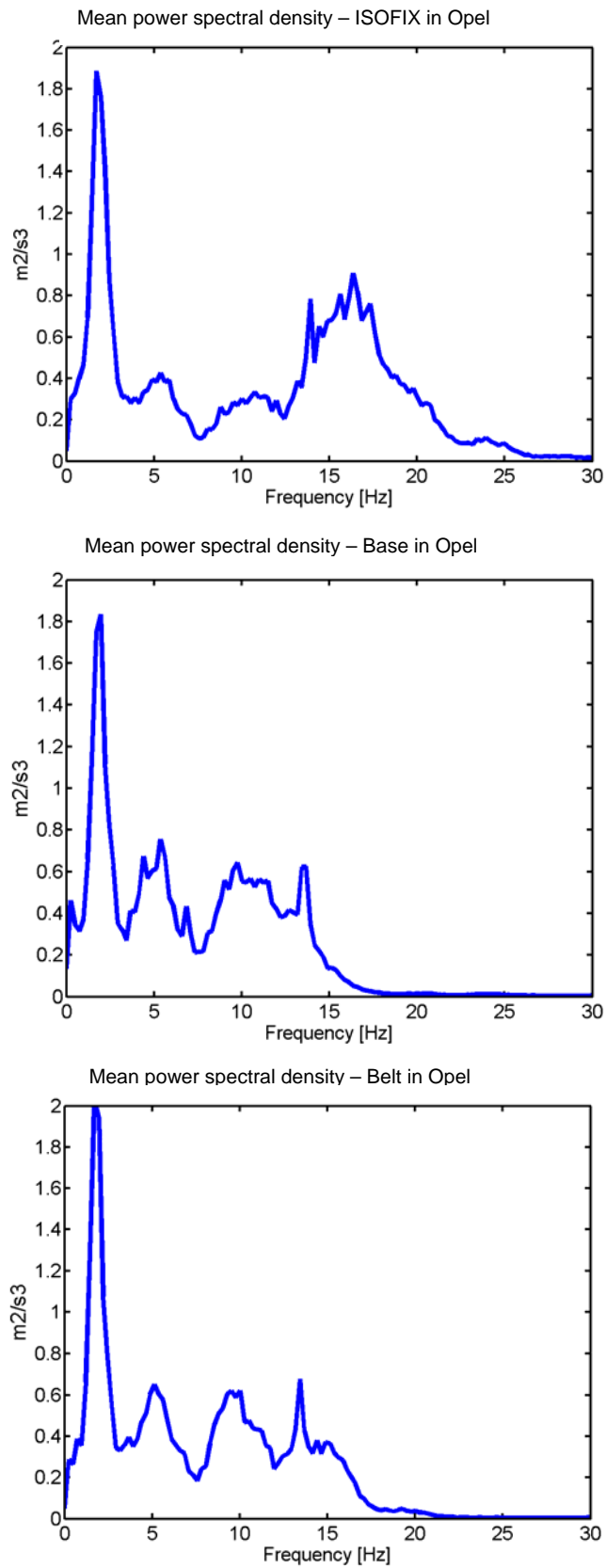


Figure 30. Mean power spectral density of the three tests for each infant safety seat in the Opel, upper ISOFIX, in the middle the seat with base and under the seat fastened with the belt

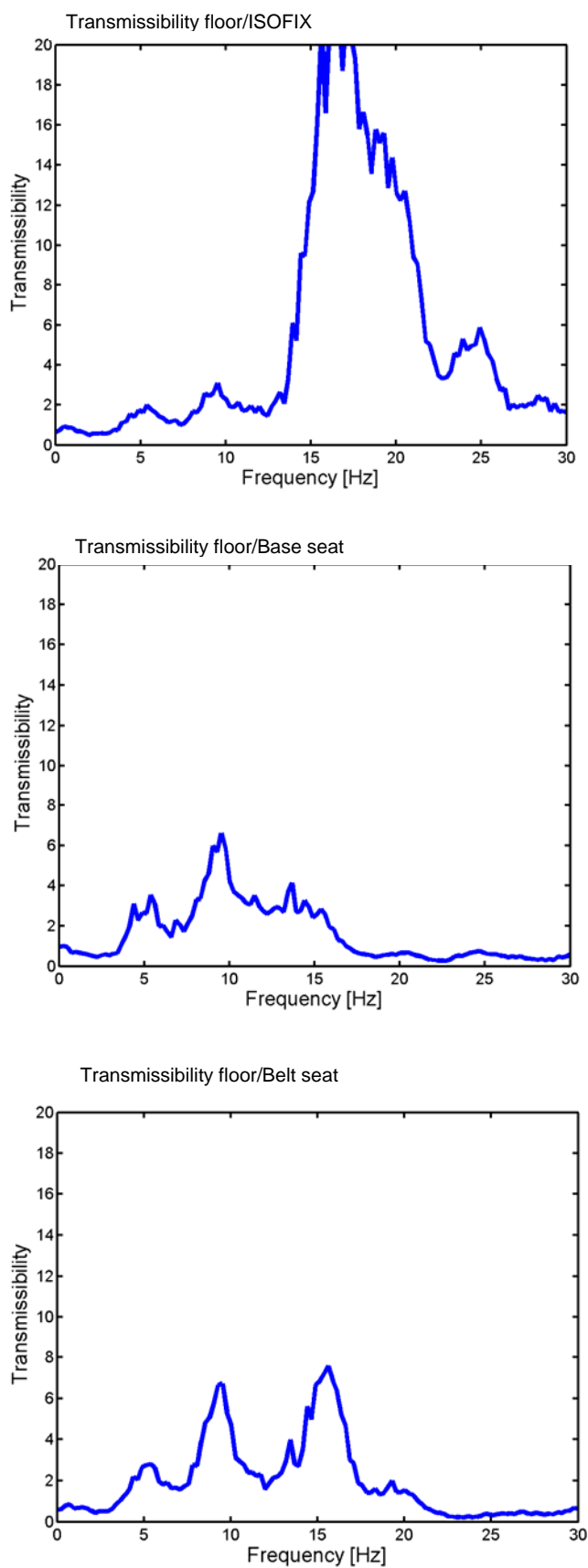


Figure 31. Mean transmissibility of the three tests for each infant safety seat in the Opel, upper ISOFIX, in the middle the seat with base and under the seat fastened with the belt

9 Discussion

The aim of this study was to describe the basis for the statements regarding long-term health effects connected with letting infants sit longer periods in infant safety seats and to find out more about the vibrational environment in infant seats.

9.1 Method discussion

In part 1 of the work a literature review and interviews were made, in part 2 vibration measurements in three different infant safety seats.

9.1.1 Part 1

Almost all literature found, describe the situation in USA. It is not obvious to transform the American conditions to European conditions. Almost all the medical experts interviewed are Swedish. In USA the problems with difficulty of breathing are mentioned together with infant safety seats, but it is not mentioned that the back could be hurt. In Europe the situation is reversed. But no literature about back problems could be found.

All answers from all asked pediatricians, nurses and physiotherapists are not presented. The quotations from pediatricians and nurses presented in the report are chosen because they summarize the situation described by the majority of the asked medical experts in a clearly way.

9.1.2 Part 2

The tested car safety seats were chosen because they were available at VTI. The three different types of seats made it possible to compare vibration levels in seats with a rigid link between the car seat and the car, with seats only standing in the rear seat fastened with the seatbelt.

The tested ISOFIX seat is not that common in Sweden, but there is not many infant seats attached with ISOFIX available yet. Volvo has an infant safety seat attached with ISOFIX but it is only approved for use in Volvo cars. Tests on more seats attached with ISOFIX would have been desirable.

There is no standard available for vibration measurements in child safety seats. The method used in this work using a dummy has probably imperfections. The dummy is not that soft as a child. The used frequency weighting are probably influenced from tests with adults. It is not obviously that this weighting is correct for children. But the frequency weightings were used to become correct values from the driver's seat and to be able to compare the driver's seat with the infant seats. A control was made and the same results were received also without the frequency weightings.

Tests were performed in two different cars. The cars had to be equipped with ISOFIX bars and the chosen car safety seats had to be approved for use in the cars. The Volvo was chosen because it is a common family car in Sweden, equipped with ISOFIX-bars and the car safety seats were approved for use in this car. One more car was chosen, to see if the same vibration

pattern was found even for another car. The Opel was available for tests, had ISOFIX bars and the car safety seats were approved for use in this car.

A point of measurement in the driver's seat was chosen because it is a usual measure and standard devices are available. A point on the floor was chosen to be able to compare the transmissibility from the floor to the different car safety seat.

The three road surfaces were chosen because they give different types of vibrations. The gravelled road and the country road give steady state vibrations; the speed bump gives a transient vibration. The gravelled road is less comfortable than the country road and should produce vibrations with higher intensity.

Similar values for repeated tests show signs of reliable measurements. The used equipment is rather old, but still used for other vibration measurements in cars. Sources of error on the floor measurement could be that the accelerometers were not correctly fastened during the tests. On the floor it was hard to find a point directly on the car body, almost over the entire floor, a carpet covers the car body.

9.2 Result discussion

It appears clearly in this report that more research is necessary; to be able to give a recommendation for how long infants can be placed in an infant safety seat without any health risks. A recommendation including a specified time is not relevant.

9.2.1 Part 1

The most common reason to why the time spent in infant seats should be limited is because of problems with the back. There are no researches made that confirm this statement. Back injuries coming from long terms in infant seats have not been observed. The statements about back problems on infants after long periods in infant seats are suggestions; there is no medical evidences known showing that infant safety seats can give any back problems.

According to Rose-Marie Hultman, nurse in Malmö in the south of Sweden, did they start to give a recommendation for the time spent in infant safety seats on child health centres for many years ago after warnings from physiotherapists. There is no written recommendation; it has only been spread oral.

Midwives and physiotherapists often say that it is harmful for the back to let infants sit more than 20-30 minutes in car safety seats. Also pediatricians and people selling infant safety seats have this opinion without being able to tell why it would do any harm; it is a theory without reason. When asking 10 salesmen from infant safety seats, if they used to give parents any time recommendations, 5 of them used to give a recommendation between 20 minutes and one hour without being able to say why this recommendation was convenient. Recommendations based on suggestions are not objectionable, evidence-based studies are needed.

Under no circumstances should parents be left with the impression that car seat use should be discouraged. The car seat remains one of the most effective products available to protect infants and children from injury and deaths in the early years of life (Bass et. al 1995).

Without evidence-based studies is a time recommendation not relevant. According to all consulted pediatricians the most important is that parents listen to the baby's signals. It is important to look after the baby in the infant seat so it does not slouch. The baby's whole back have to be supported by the infant seat, not only at the shoulders and at its buttocks. In a shrunken position their upper airways can be narrowed and that can reduce oxygen desaturation. It is also important that it is not too hot for the baby, and that it is properly fastened in the infant seat.

Either people are travelling with infants or without, when travelling for extended periods of time, it is important to take breaks. Especially the driver should take a 10-15 minute break after spending 2 hours on the road.

Effectiveness of correctly used child safety seats are well documented, but there is also a need for more research on the optimum design of child restraints and the effect of positioning on the respiratory physiology of young infants.

9.2.2 Part 2

Experimental acceleration measurements were performed for six combinations of automobile and infant safety seat while driving over three different road surfaces. The damping of the three different child seat systems was found to be less effective than the damping in the driver's seat. The levels measured in the infant safety seat were higher than those in the driver's seat for all tests. These results agree with the results from vibration measurements in child safety seats presented by Giacomini 2000 and 2003.

If the r.m.s values calculated for the tests on country road are compared with the values for human sensibility in table 2, some values for infant seats are higher than 0.5 m/s^2 , which means fairly uncomfortable. The sensitivity is from an adult's point of view and it is hard to say anything about the experience of an infant.

The r.m.s values for the tests on gravelled road are all high for the infant seats. The values for the ISOFIX seat were higher than the other infant seats, but the difference was not that high in relation to the difference between the infant seats and the driver's seat.

Spectral analysis showed that the infant seat attached with ISOFIX have better attenuation than the other two infant seats attached with the seat belt for frequencies between 1 and 15 Hz, but frequencies over 15 Hz were strongly amplified.

Of course, little is known about how the vibrations are experienced by infants. According to frequency weighting filters defined in ISO 2631-1, 16 Hz represents the upper limit of the region of greatest human sensitivity to whole-body vibration in the z-direction.

Long-term health effects from vibrations strike people working in vibrating vehicles many hours a day and in many years. The vibrations reaching infants in infant safety seats can likely not give infants long term health effects. On the other hand the comfort for the children could be better.

9.3 Future work

Future studies could be further investigation how the attenuation of vibrations in the infant seats can be better. The vibrations in all three infant seats tested have higher amplitude and attenuate frequencies under 25 Hz less than the driver's seat.

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www.ne.se
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www.færdselssikkerhed.dk
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www.vti.se
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Vägverket, Swedish Road Administration
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Email

Ekström Anne-Berit <anne-berit.ekstrom@vgregion.se> ”Ang: VB: Normal utveckling” [Email]. Personal Email to Malin Nilsson 2005-03-29

Hultman Rose-Marie <rose-marie.hultman@skane.se> “SV: Babyskydd” [Email]. Personal Email to Malin Nilsson 2005-02-22

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Appendices

A1 Literature search – Used search terms

- A:** Baby/ babies /toddler /infant /infancy /infant /newborn
- B:** Neck/back/cervical spine/ spinal stress /Spondylolisthesis/ apnea /sleep /Respiration /oxygen desaturation /breath /ekg /heart /electrocardio* /pulse /bradycardia /cardiorespiratory
- C:** Posture /sitting semi-reclined /recline /halfway back /30-45 degree angle /extended use /prolong /minutes /time
- D:** Car seat /Child safety seat /Safety seat /Child seat /Infant restraint /Child restraint system /car seat /infant seat /baby seat /rearward-facing seat /rearward facing/forward-facing seat /Carycot /lateral car bed /transverse infant bed /occupant restraint /passive safety system /safety belt /infant equipment /infant carrier

TRAX, TRIS, ITRD and SAE:

A in combination with **B, C and D.**

Medline:

A meshterm in combination with **B, C and D.**

A2 Questions to pediatricians, nurses, physiotherapists

1. Have you heard some time recommendations for how long an infant can be placed in an infant safety seat?
2. Have you heard about problems with letting an infant sit longer periods in an infant safety seat?
3. Do you think that the infant seats can cause back injuries?

In Swedish

1. Har du hört någon rekommendation innehållande en specifik tid för hur länge spädbarn klarar av att sitta i babyskydd?
2. Har du hört talas om problem som har uppstått pga. att spädbarn har suttit länge i babyskydd?
3. Tror du att det kan vara skadligt för spädbarns ryggar att sitta långa perioder i babyskydd?

In German

1. Haben Sie Empfehlungen gehört, von wie lange ein Baby in einer Babyliedgeschale sitzen kann?
2. Haben Sie gehört von Schäden, gekommen, wenn ein Kind lange in einer Babyliedgeschale gesessen hat?
3. Glauben Sie, dass Babyliedgeschalen, das Rücken des Babys schaden kann?

Number of respondents:

Swedish pediatricians	18
Swedish nurses	3
Swedish physiotherapists	10
German pediatricians	3
Danish pediatricians	1
American pediatricians	1
<hr/>	
Total	36

A3 References to possible reasons why the time spent in infant seats would be limited

A3.1 Literature

In 1990, the AAP Committee on Accident and Poison prevention issued a policy for safe transportation of newborns at Hospital discharge. One point in the policy is:

Hospitals should develop a policy to ensure provision of a period of observation in a car safety seat before hospital discharge for each infant born at <37 weeks' gestation to monitor for possible apnea, bradycardia, or oxygen desaturation.

American Academy of Pediatrics, Committee on Accident and Poison Prevention. Safe transportation of newborns discharges from the hospital. Pediatrics 1990,86 486-487

Ulrike Doll, Barbara Maurer-Burkhard. Autokindersitze - Sicherheit für unsere Kinder. Verlag Hans Huber, Bern, 1998

"(...) Die Babyschalen sollen grundsätzlich für jeden Transport der Kinder im Pkw verwendet werden und nicht zum häufigen Gebrauch als Sitzmöglichkeit oder als Schlafstätte. In der Wohnung sollten diese Schalen jedoch nicht als Sitz- oder Schlafgelegenheit genutzt werden. Erst im 9.-11. Lebensmonat ist die Entwicklung der Kinder soweit fortgeschritten, dass sie selbständig sitzen können. Um Schäden an der Wirbelsäule vorzubeugen, sollten die Kinder nicht zu früh und vor allem nicht "passiv" hingestellt werden. Für die normale Entwicklung ist das Liegen/ Spielen auf einer ebenen Unterlage am geeigneten, da sie den größtmöglichen Bewegungsfreiraum für das Kind bietet."

In Norvenius' dissertation from 1997, Sudden infant death syndrome in Sweden in 1973-1977 and 1979 is reported that some cases of SIDS had occurred in cars. This was before infant safety seats became popular. Infant safety seats are mentioned as a risk factor for SIDS. When the infant safety seats became popular, the cases of SIDS increased.

In Giacomini's vibration measurements from 2000 vibrations is mentioned as a possible risk to human health. And his study showed that the vibration levels were found to be higher in infant's seats than in the driver's seat.

A3.2 Information from people working with child safety

In Austria and Denmark information from traffic safety organizations say that too much time in an infant safety seat can cause problems with the back.

0-13 MÅNEDER

VÆGT INDTIL 13 KG



BABYSTOLE

Det sikreste er en bagudvendt baby-stol. Den kan bruges lige fra fødslen. Skal I på en længere køretur, kan din baby godt tåle at sidde/ligge 1½ - 2 timer i stolen uden risiko for rygproblemer. Ellers anbefaler vi højst 20-30 minutter om dagen de første par

måneder, så din babys ryg ikke belastes for meget. En del stole kan vippe, så babyen ligger mere ned, hvilket kan være en fordel, hvis du skal køre langt.

Husk, at en bagudvendt stol aldrig må placeres ved en airbag.

Figure 32. From leaflet "Børn i bilen", Rådet for Større Faerdselssikkerhed
http://www.faedrselssikkerhed.dk/db/files/boernibilen_2.pdf

From „Sicher unterwegs“ – Kindersicherheit im Auto, Österreichischen Bundesministeriums für Verkehr, Innovation und Technologie:

- **In den ersten 4 Monaten nur die notwendigsten Autofahrten mit dem Kind durchführen.**
- **Zu langer Gebrauch außerhalb des Autos (z.B. beim Shopping als Tragetäschenersatz) kann durch die gebeugte Haltung die gesunde Entwicklung Ihres Kindes gefährden.**

A4 Results from measurements in driver's seat and on the floor Country road 50 km/h

When comparing r.m.s values from the driver's seat with r.m.s values from the floor from all tests on country road with the Volvo, the r.m.s values in the driver's seat were higher in 5 of 7 tests.

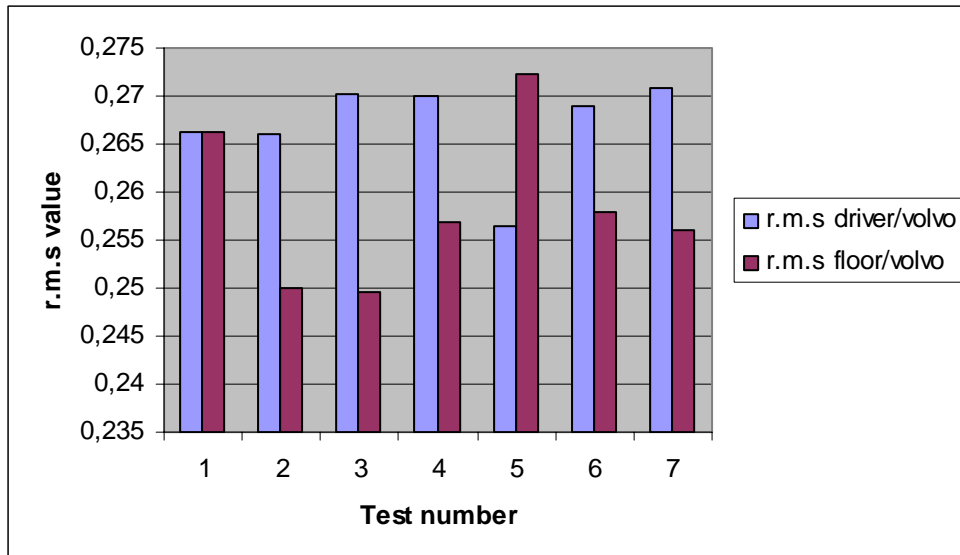


Figure 33. R.m.s values driver's seat and floor in Volvo from test runs on Country road 50 km/h

For the Opel the r.m.s values seem to be more reliable. When comparing r.m.s values from the driver's seat with r.m.s values from the floor from all tests on country road with the Opel, the r.m.s values on the floor were higher in all tests.

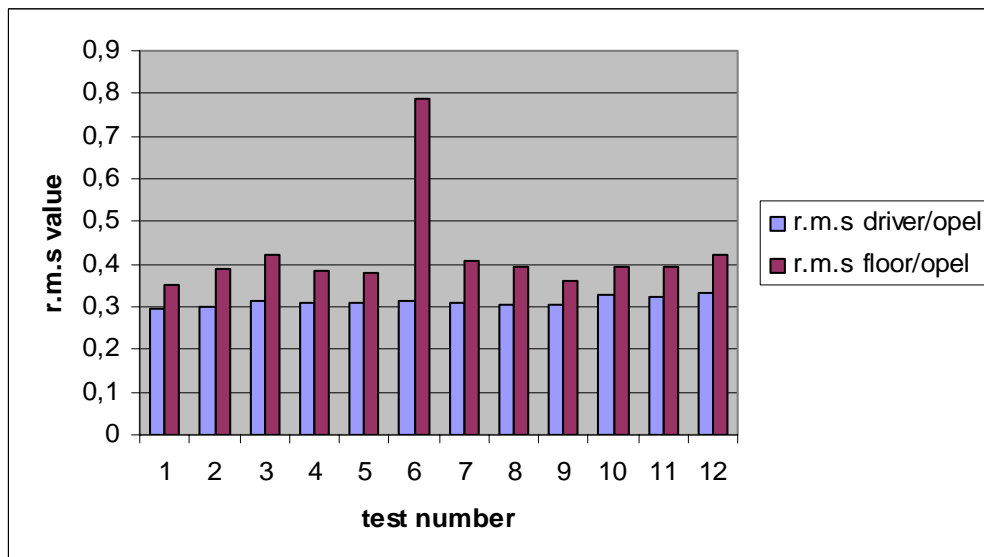


Figure 34. R.m.s values driver's seat and floor in Opel from test runs on Country road 50 km/h

A5 Results from vibration measurements in x,y and z direction.

R.m.s values from test runs on country road in 50 km/h ISOFIX

	Min x	Max x	Rms x	Crest x
Volvo	-0,5856	0,6518	0,1401	4,6514
	-0,9668	0,9718	0,2089	4,6509
	-1,0551	1,2883	0,1703	7,5659
Mean	-0,869	0,971	0,173	5,623
Std	0,250	0,318	0,034	1,683
Opel	-0,8582	0,7897	0,136	5,8069
	-1,0555	1,0095	0,1611	6,2665
	-0,9655	0,9261	0,1592	5,8182
	-1,2476	11,037	0,1691	6,1336
Mean	-1,032	3,441	0,156	6,006
Std	0,165	5,065	0,014	0,230
	Min y	Max y	Rms y	Crest y
Volvo	-0,679	0,7406	0,1841	4,0233
	-1,242	0,9718	0,2089	4,6509
	-1,0887	1,5056	0,2152	6,9969
Mean	-1,003	1,073	0,203	5,224
Std	0,291	0,392	0,016	1,567
Opel	-1,5352	1,6727	0,2245	7,4519
	-1,608	2,0708	0,2631	7,8719
	-1,8632	1,1685	0,258	4,5294
	-1,5879	1,996	0,2639	7,5633
Mean	-1,649	1,727	0,252	6,854
Std	0,146	0,410	0,019	1,560
	Min z	Max z	Rms z	Crest z
Volvo	-4,5283	4,7871	0,5454	8,7774
	-3,4055	4,2366	0,5174	8,1886
	-2,6281	3,2342	0,4708	6,87
Mean	-3,521	4,086	0,511	7,945
Std	0,955	0,787	0,038	0,977
Opel	-4,0441	3,6188	0,4618	7,8355
	-4,8558	4,3744	0,5219	8,3818
	-4,6185	3,6616	0,5862	6,2459
	-4,9654	4,7837	0,5311	9,0077
Mean	-4,621	4,110	0,525	7,868
Std	0,411	0,567	0,051	1,183

Base				
	Min x	Max x	Rms x	Crest x
Volvo	-1,1279	0,8903	0,1669	5,3349
	-1,0742	1,3447	0,1724	7,8011
Mean	-1,101	1,118	0,170	6,568
Std	0,038	0,321	0,004	1,744
Opel	-0,9058	1,0262	0,1514	6,7799
	-1,5187	0,9535	0,1656	5,7567
	-1,0709	1,1772	0,1775	6,6338
	-1,4683	1,0146	0,1711	5,9294
Mean	-1,241	1,043	0,166	6,275
Std	0,300	0,095	0,011	0,507
	Min y	Max y	Rms y	Crest y
Volvo	-1,2819	1,0562	0,2174	4,8593
	-0,8675	1,1158	0,2217	5,034
Mean	-1,075	1,086	0,220	4,947
Std	0,293	0,042	0,003	0,124
Opel	-1,3455	1,1615	0,2189	5,3062
	-1,1726	1,3566	0,2367	5,731
	-1,4345	1,9093	0,2491	7,6643
	-1,283	1,541	0,2462	6,2584
Mean	-1,309	1,492	0,238	6,240
Std	0,110	0,318	0,014	1,026
	Min z	Max z	Rms z	Crest z
Volvo	-2,4421	2,8701	0,3946	7,2738
	-2,6583	2,7925	0,408	6,8444
Mean	-2,550	2,831	0,401	7,059
Std	0,153	0,055	0,009	0,304
Opel	-3,2348	3,0033	0,4796	6,2618
	-4,8045	4,5197	0,5149	8,777
	-3,4722	3,9589	0,5458	7,2531
	-5,1281	4,666	0,5219	8,9404
Mean	-4,160	4,037	0,516	7,808
Std	0,945	0,753	0,027	1,281

Belt				
Volvo	Min x	Max x	Rms x	Crest x
	-1,0996	0,9338	0,1804	5,1766
	-1,1489	1,4089	0,1949	7,2285
Mean	-1,124	1,171	0,188	6,203
Std	0,035	0,336	0,010	1,451
Opel	-1,3539	1,1058	0,1687	6,5565
	-0,9546	0,8089	0,1479	5,4707
	-1,1728	0,8564	0,1624	5,2741
	-0,7437	0,8238	0,165	4,9923
Mean	-1,056	0,899	0,161	5,573
Std	0,265	0,139	0,009	0,684
	Min y	Max y	Rms y	Crest y
Volvo	-1,3651	1,1274	0,1754	6,4272
	-0,9246	1,5092	0,1851	8,1538
Mean	-1,145	2,637	0,180	7,291
Std	0,311	0,270	0,007	1,221
Opel	-1,0058	1,452	0,2165	6,706
	-0,9767	0,961	0,1838	5,2292
	-1,103	1,6529	0,2188	7,5535
	-1,0355	1,2653	0,2264	5,5887
Mean	-1,030	1,333	0,211	6,269
Std	0,054	0,294	0,019	1,062
	Min z	Max z	Rms z	Crest z
Volvo	-3,708	2,6611	0,406	6,5553
	-2,8178	3,197	0,4067	7,8616
Mean	-3,263	2,929	0,406	7,208
Std	0,629	0,379	0,000	0,924
Opel	-3,9014	4,5636	0,5106	8,9377
	-3,4046	3,727	0,4649	8,0167
	-4,6169	3,8319	0,5198	7,3721
	-3,7359	4,0918	0,5051	8,1018
Mean	-3,915	4,054	0,500	8,107
Std	0,512	0,373	0,024	0,642

R.m.s values from test runs on gravelled road in 30 km/h**ISOFIX**

	Min x	Max x	Rms x	Crest x
Volvo	-1,6738	1,7767	0,4266	4,1647
	-1,9705	1,7714	0,431	4,1988
	-1,7221	1,7208	0,429	4,011

Mean	-1,789	1,756	0,429	4,125
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Opel	-1,6817	1,9399	0,3577	5,4233
	-1,6478	2,9839	0,401	7,4413
	-2,0205	2,8622	0,4045	7,0762

Mean	-1,783	2,595	0,388	6,647
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	Min y	Max y	Rms y	Crest y
Volvo	-2,0263	2,8892	0,5197	5,5597
	-2,0665	1,9978	0,4758	4,1988
	-2,1305	2,0166	0,4882	4,1303

Mean	-2,074	2,301	0,495	4,630
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Opel	-2,6265	2,5036	0,5056	4,9518
	-2,6831	2,411	0,4911	4,9091
	-3,4704	3,4151	0,5365	6,365

Mean	-2,927	2,777	0,511	5,409
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	Min z	Max z	Rms z	Crest z
Volvo	-6,5984	7,8713	1,7174	4,5833
	-6,9545	9,5638	1,6768	5,7036
	-7,0959	8,8317	1,7087	6,1688

Mean	-6,883	8,756	1,701	5,485
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Opel	-8,995	11,4523	1,8085	6,3324
	-8,3096	11,0739	1,7083	6,4823
	-8,8341	11,4135	1,8078	6,3134

Mean	-8,713	11,313	1,775	6,376
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Base				
	Min x	Max x	Rms x	Crest x
Volvo	-1,4162	1,343	0,3622	3,7079
	-1,6422	1,5757	0,3925	4,0145
	-1,9899	1,5182	0,3993	3,8026
Mean	-1,683	1,479	0,385	3,842
Opel	-1,7993	2,0202	0,3467	5,8265
	-1,8264	1,8431	0,3579	5,1496
	-1,754	2,3659	0,3408	6,9425
Mean	-1,793	2,076	0,348	5,973
	Min y	Max y	Rms y	Crest y
Volvo	-1,5648	1,591	0,4202	3,7865
	-1,9157	2,1282	0,4622	4,6048
	-1,9612	2,1354	0,4584	4,6588
Mean	-1,814	1,952	0,447	4,350
Opel	-3,3158	2,7259	0,4786	5,6958
	-2,7099	2,8076	0,5247	5,3507
	-2,8941	2,5317	0,4708	5,3775
Mean	-2,973	2,688	0,491	5,475
	Min z	Max z	Rms z	Crest z
Volvo	-4,8407	4,9188	1,1841	4,154
	-5,0516	5,1895	1,2694	4,088
	-4,549	5,6597	1,2734	4,4446
Mean	-4,814	5,256	1,242	4,229
Opel	-7,5177	11,6166	1,6706	6,9537
	-7,8385	10,2085	1,6166	6,3147
	-7,4583	11,3403	1,4344	7,906
Mean	-7,605	11,055	1,574	7,058
Belt				
Volvo	Min x	Max x	Rms x	Crest x
	-1,3785	1,4427	0,3528	4,0894
	-1,594	1,6075	0,3454	3,5007
	-1,5154	1,7927	0,375	4,7808
Mean	-1,496	1,614	0,358	4,124

Opel	-1,3937	1,5187	0,3127	4,8565
	-1,3583	1,9744	0,2944	6,7064
	-1,2438	1,319	0,2981	4,4253
Mean	-1,332	1,604	0,302	5,329
	Min y	Max y	Rms y	Crest y
Volvo	-1,1389	1,1599	0,3049	3,8041
	-1,429	1,209	0,3454	3,5007
	-1,3195	1,4177	0,3501	4,0493
Mean	-1,296	3,787	0,333	3,785
Opel	-2,4101	2,012	0,4632	4,3438
	-1,7052	1,6598	0,3971	4,1801
	-2,4041	1,9483	0,3991	4,8814
Mean	-2,173	1,873	0,420	4,468
	Min z	Max z	Rms z	Crest z
Volvo	-6,6587	6,863	1,2788	5,3669
	-5,1297	5,211	1,3139	3,966
	-4,9365	5,2437	1,3091	4,0056
Mean	-5,575	5,773	1,301	4,446
Opel	-7,2905	9,1832	1,7562	5,2289
	-8,2914	10,8768	1,7002	6,3972
	-8,6479	10,7004	1,6915	6,3258
Mean	-8,077	10,253	1,716	5,984

R.m.s values from test runs over a speed bump in 30 km/h

ISOFIX

	Min x	Max x	Rms x	Crest x
Volvo	-1,295	1,4457	0,2617	5,5239
	-1,5105	1,5023	0,3439	4,3691
	-1,6512	1,6323	0,3262	5,0041

Mean -1,486 1,527 0,311 4,966

Opel	-1,405	1,3751	0,327	4,2053
	-1,3969	1,5228	0,4188	3,6382
	-1,6584	1,5223	0,3753	4,0558

Mean -1,487 1,473 0,374 3,966

	Min y	Max y	Rms y	Crest y
Volvo	-0,7676	0,6404	0,2129	3,0087
	-0,6607	0,6833	0,2415	2,8291
	-0,8041	0,662	0,2082	3,1791

Mean -0,744 0,662 0,221 3,006

Opel	-1,1595	1,2187	0,2618	4,6548
	-1,2183	1,5772	0,4251	3,71
	-0,8315	1,2965	0,2774	4,6741

Mean -1,0698 1,3641 0,3214 4,3463

	Min z	Max z	Rms z	Crest z
Volvo	-4,056	4,892	0,6974	7,0149
	-3,6588	4,0278	0,8071	4,9905
	-3,2612	4,1328	0,7368	5,6089

Mean -3,659 4,351 0,747 5,871

Opel	-4,9487	7,8105	1,3333	5,8579
	-6,2855	9,306	1,4524	6,4072
	-6,1007	9,1963	1,5063	6,1054

Mean -5,778 8,771 1,431 6,124

Base

	Min x	Max x	Rms x	Crest x
Volvo	-1,5114	1,3954	0,3284	4,249
	-1,2688	1,2843	0,3501	3,6685
	-1,4065	1,2456	0,329	3,7859

Mean -1,396 1,308 0,336 3,901

Opel	-1,025	1,3263	0,3206	4,1363
	-1,1186	1,1731	0,2802	4,1859
	-1,5448	1,2872	0,4136	3,112

Mean	-1,229	1,262	0,338	3,811
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Volvo	Min y	Max y	Rms y	Crest y
	-0,7362	0,6987	0,3518	1,9857
	-1,1944	0,8619	0,32264	2,6403
	-0,4323	0,5215	0,216	2,414

Mean	-0,788	0,694	0,297	2,347
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Opel	-1,3858	1,2244	0,3692	3,3162
	-1,5647	1,2939	0,393	3,2922
	-1,1885	1,3716	0,3838	3,5741

Mean	-1,380	1,297	0,382	3,394
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Belt Volvo	Min x	Max x	Rms x	Crest x
	-1,2239	1,4045	0,3385	4,1492
	-1,2992	1,5579	0,2748	5,6695
	-0,9951	1,3833	0,3885	3,5603

Mean	-1,173	1,449	0,334	4,460
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Opel	-1,1949	0,9789	0,2702	3,6235
	-0,7234	1,087	0,2781	3,9079
	-0,9994	1,0294	0,3022	3,4065

Mean	-0,973	1,032	0,284	3,646
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Volvo	Min y	Max y	Rms y	Crest y
	-0,6119	0,3836	0,1726	2,223
	-0,6937	0,5115	0,1421	3,5989
	-0,5172	0,7826	0,244	3,2072

Mean	-0,608	1,678	0,186	3,010
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Opel	-0,9946	0,7409	0,2431	3,0482
	-0,9442	1,2502	0,285	4,3867
	-0,9578	0,9784	0,2859	3,4224

Mean	-0,966	0,990	0,271	3,619
	Min z	Max z	Rms z	Crest z
Volvo	-3,1735	3,6037	0,7064	5,1011
	-3,6705	3,9302	0,8239	4,7701
	-3,0909	2,8397	0,6842	4,1503
Mean	-3,312	3,458	0,738	4,674
Opel	-3,1816	4,8302	0,8382	5,7628
	-4,5962	6,0055	0,9251	6,492
	-4,7748	6,3411	1,2053	5,2612
Mean	-4,184	5,726	0,990	5,839

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HUVUDKONTOR/HEAD OFFICE

LINKÖPING

POST/MAIL SE-581 95 LINKÖPING

TEL +46 (0)13 20 40 00

www.vti.se

BORLÄNGE

POST/MAIL BOX 760

SE-781 27 BORLÄNGE

TEL +46 (0)243 446 860

STOCKHOLM

POST/MAIL BOX 6056

SE-171 06 SOLNA

TEL +46 (0)8 555 77 020

GÖTEBORG

POST/MAIL BOX 8077

SE-402 78 GÖTEBORG

TEL +46 (0)31 750 26 00