Child Restraint Systems

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Please note: The studies included in this synopses were selected from those identified by a systematic literature search of specific databases (see supporting document). The main criterion for inclusion of studies in this synopsis and the DSS was that each study provides a *quantitative effect estimate*, preferably on the number or severity of crashes or otherwise on road user behaviour that is known to be related to the occurrence or severity of a crash. Therefore, key studies providing qualitative information might not be included in this synopsis.

1 Summary

Reed, S., June 2017

1.1 COLOUR CODE: GREEN

From the literature which considers the safety effects of child restraint systems, it was found that overall the use of child restraint systems affects safety in a positive way. The results of a meta-analysis show clear consistency in the positive benefits of child restraint systems despite individual studies reporting similarly positive but less robust/non-significant results. Overall it is possible to say that child injury risk is lowest for appropriate child restraint use, higher for inappropriate child restrain use and highest when not using child restraints.

1.2 KEYWORDS

Child restraint systems; CRS; Booster seat use; Child restraints; Car safety seat; Child passenger safety legislation; injuries; children; infants; Child passengers; Motor vehicle crashes; traumatic brain injury.

1.3 ABSTRACT

Child restraint systems (CRS) aim to reduce injuries to children in motor vehicle crashes by providing both additional impact protection and optimal restraint geometry to a child passenger. Typically countries regulate the use of child restraint systems through safety laws with most developed countries stipulating the use of a CRS up to the age of 2 or more. Studies on child restraint performance are normally derived from the analysis of real world collision data, hospital information and public health data, and can therefore form large samples and robust results. The results show that the use of an appropriate and correctly used child restraint reduces the risk of death and injuries compared to a child either using a CRS incorrectly, using a standard seat belt or being completely unrestrained. Despite the overall positive effect on road safety there is evidence in some instances, such as comparing a correctly used child restraint to a standard seatbelt, that fatalities and very serious injuries are not significantly reduced for infants involved in higher speed motor vehicle crashes or where intrusion into the interior space is present.

1.4 BACKGROUND

1.4.1 What are child restraint systems?

Child restraint systems (CRS) aim to reduce injuries to children in motor vehicle crashes by providing both additional impact protection and optimal restraint geometry to a child passenger. There are a range of child seats commercially available that cater for all child ages and sizes, some forward facing, some rear facing and with a range of ways in which they are installed in a vehicle (ISOFIX or using standard belt webbing), however the general concepts are the same, to provide harnesses that are better suited to a child of that size/weight or to adapt a standard belt to the required size while also bringing in additional benefits in terms of 'wings' to support and contain a child's head and upper body in the event of a side impact or rollover.

1.4.2 How do child restraint systems affect road safety?

Child restraint systems affect road safety in a positive way by providing an additional level of protection to a child that a standard vehicle and seat belt system cannot. An optimised harness/belt position over a child can reduce the risk of abdominal or spinal injuries brought about by 'jack knife' bending or sliding beneath a poorly fitted belt. In addition the semi-enclosed design of CRS can reduce child injuries due to impact of the head with parts of the vehicle interior.

1.4.3 Which safety outcomes are affected by child restraint systems?

The measures recorded for best positioning booster seats are normally in terms of injury outcomes, ranging from any injury occurring through to fatalities.

1.4.4 How are the effects of child restraint systems studied?

The effect of child restraint systems are generally studied in terms of an injury outcome measure although the specifics of the outcome vary between studies depending on the study focus; for example, traumatic brain injury and risk of head injury in general (Stewart, 2013) are studied in isolation whereas in other studies the risk of fatal injuries (Ma, 2012) or injuries in general (Brubacher, 2015) are the main outcome measures.
For all studies the fatality risk or injury risk are used in case control, matched or time series studies to investigate whether fatalities or injuries are reduced when a child is restrained correctly in a suitable child restraint system. The data is predominantly examined using risk ratios or odds ratios for the change in outcome with CRS use, with tests of significance typically used.
The data from the meta-analysis in this study were predominantly from the USA (18/27) with the remainder made up of studies from Sweden (6/27), Australia (2/27) and Canada (1/27). The three remaining studies considered in this synopsis were also from the United States and Canada.

1.5 OVERVIEW OF RESULTS

Overall, the results showed that the use of child restraint systems do reduce fatality risk and injury risk rates compared to children restrained in standard three point seatbelts or completely unrestrained.

The likely injury mechanisms for unrestrained children involved in motor vehicle collisions are predominantly down to contact with interior components or ejection from the vehicle. The results from the studies in this synopsis support this view as the difference in injury outcomes between using any restraint type, an inappropriate child restraint and an appropriate child restraint do not differ hugely suggesting that injury outcomes are associated with any form of restraint and not necessarily the restraint type alone.

Despite this, the outcome of the meta-analysis indicates that injury risk is lowest for appropriate child restraint use, higher for inappropriate child restraint use and highest when not using child restraints; there are no systematic differences in these results based on the age of the child.

1.6 NOTES OF ANALYSIS METHODS

Most studies used large sample sizes for investigation, typically drawn from real world large scale collision datasets or hospital records. Data samples were usually in the region 1000+ children/motor vehicle crashes (for example, Ma et al, 2012, n=7633 children) however for a number of the calculated outcomes this number was significantly reduced due to additional sampling requirements (Stewart et al, 2015, n=119 children split between cases and controls). The topic of "child restraint systems" has been well studied as a measure.

2 Scientific Overview

1.1 LITERATURE REVIEW

1.1.1 DESCRIPTION OF AVAILABLE STUDIES

Four studies were identified for their inclusion in the synopsis of the measure "child restraint systems " with one of these a collection of 27 studies brought together to form a meta-analysis. In the four studies, a variety of outcome measures for child restraint systems were investigated, from the risk of death to any injury occurring over a number of exposure conditions, from restrained correctly in an appropriate CRS to completely unrestrained.

The meta-analysis brings together the results of 27 similar studies on child restraint systems. The meta-analysis typically analysed real world collision data, using relatively large sample sizes and applying a case control or matched study design to compare groups of exposed and non-exposed children. The meta-analysis makes distinctions between specific types of child restraints with most studies making comparisons between legally appropriate (or recommended) child restraints and either seat belt use only, inappropriate child restraints or no child restraints. Which CRS is appropriate or not depends on the age and weight of the child.

The majority of studies included in the meta-analysis were from the United States (18/27) with the remainder made up of studies from Sweden (6/27), Australia (2/27) and Canada (1/27) with studies ranging from the late 1970s when child occupant protection was in its infancy, right up to studies as recent as 2012. The studies included in the meta-analysis have been augmented by the most recent studies available on the subject from Canada (2015) and the United States (2012 and 2013).

Table 1 shows the overview of these coded studies.

Table 1: Descriptions of coded studies on use of child restraint systems

Author, Year, Country	Sample, method/design and analysis		Reference group	Additional information on analysis
Høye, A.,2016, USA, Sweden, Australia, Canada	Meta-analysis (random effects and fixed effects), which included observational case-control and cross-sectional studies (27 studies total).	Percentage change in injury and fatalities between child restraint system	Percentage of injuries and fatalities in other restraint conditions.	Percentage change was investigated for injury, minor injury, severe injury and fatality for a range of child age groups.
Brubacher et al, 2016, Canada	Observational time series study with injury rates among children analysed using multiple linear regression models. Sample of ~12000 injuries in children aged 0 to 14.	Injury rates in children in motor vehicle crashes in age appropriate infant or booster seats	Injury rates in children in motor vehicle crashes in inappropriate restraints	Results adjusted using children aged nine to 14 years of age
Ma et al., 2012, USA	Observational cross sectional study using real world collision data between 1996 and 2005 involving child passengers between 0 and 12	Odds ratio of non-fatal and fatal injuries for inappropriately restrained infant, toddler, young child	Odds ratio of non-fatal and fatal injuries for appropriately	-

Author, Year, Country	Sample, method/design and analysis		Reference group	Additional information on analysis
	years old (n=7633)	and older child	restrained infant, toddler, young child and older child	
Stewart et al, 2015, USA	Observational cross sectional study using real world collision data and public health data involving child passengers in motor vehicle crashes (n=833)	Odds ratio of trauma care attendance for inappropriately restrained infant	Odds ratio of trauma care attendance for appropriately restrained infant	

1.1.2 STUDY RESULTS

Overall, the results across all four studies, including the meta-analysis, showed that the use of child restraint systems do reduce fatality risk and injury risk rates compared to children restrained in standard three point seatbelts or completely unrestrained.

Høye (2015) undertook a meta-analysis of twenty seven studies investigating the safety effects of children restrained in child restraint systems and found significant reduction in the percentage of fatal injuries (ranging between -81% to -34%), Serious injuries (ranging between -72% to -35%) and slight injuries (ranging between -58% to -25%) for children restrained appropriately in CRS.

Brubacher et al. (2016) investigated the effect of child restraint system use for samples of young children compared to an older control group. The study found that the use of child seats was associated with a 13% reduction in the monthly rate of injuries in zero to three-year-old children compared to the control group.

Ma et al. (2012) looked at differences in protection an appropriately used child restraint provides for a range of age groups compared to inappropriate restraint use or no restraint use at all. Results indicate that the odds of an inappropriately restrained infant, toddler or young child receiving non-fatal injuries in a motor vehicle collision are higher than children in appropriate CRS, however these are non-statistically significant. The same pattern holds true for fatal injuries which show that unrestrained or inappropriately restrained children are more likely to receive this level of injury compared to appropriate CRS use.

Stewart et al. (2015) investigated the odds of properly restrained child passengers attending a trauma centre after a motor vehicle collision compared to improperly restrained children. Results show that the odds of a properly restrained infant presenting to a trauma centre with injuries after a motor vehicle collision are 12.7 times lower than that of an improperly/unrestrained infant

Table 5 in the supporting document presents an overview of the information on the main outcome of coded studies on child restraint system use.

1.1.3 META ANALYSIS OF DATA FOR USE OF CHILD RESTRAINT SYSTEMS

Table 2 outlines the main results of the existing meta-analysis of the 27 child restraint system studies undertaken by Høye (2015).

Table 2 Random effects meta-analysis for child restraint effects on percentage injury reduction compared to unrestrained child (Høye, 2015)

Variable	Estimate	95% CI	Statistically significant?
Child using any restraint (all injury severities)	-52%	(-92%, -16%)	Y
Child appropriately restrained in CRS (all injury severities)	-54%	(-86%, 20%)	Y

1.2 CONCLUSION

Overall, it was found that the use of child restraint systems do not appear to affect safety in a negative way and in the majority of studies used for this synopsis, provide positive benefits to road safety. There are however indications that using any restraint type, including a standard three point seatbelt or a child restraint used inappropriately can lead to improvements in safety over an unrestrained child occupant, suggesting that the risk of injury is down to contact with interior components or ejection from the vehicle and not the restraint type alone. Despite this the outcome of the meta-analysis indicates that injury risk is lowest for appropriate child restraint use, higher for inappropriate child restrain use and highest when not using child restraints; there are no systematic differences in these results based on the age of the child.

In the individual coded studies the results did find that the use of an appropriate and correctly used child restraint can reduce the risk of admittance to a trauma care or emergency department and reduce non-fatal injuries for children aged between zero and eight years old. Results for appropriately restrained children compared to inappropriately restrained children do show a broadly positive picture however the effect is smaller with some of the results not statistically significant.

Despite the overall positive effect on road safety there is evidence in some instances, such as comparing a correctly used child restraint to a standard seatbelt, that fatalities and very serious injuries are not significantly reduced for infants involved in higher speed motor vehicle crashes or where intrusion into the interior space is present.

3 Supporting Documents

1.3 DESCRIPTION OF THE STUDIES IDENTIFIED FOR INCLUSION IN SYNOPSIS

In total, four studies were identified as being the most relevant for this synopsis on child restraint systems.

Høye (2015) undertook a meta-analysis of twenty seven studies investigating the safety effects of children restrained in child restraint systems and found significant reduction in the percentage of fatal injuries (ranging between -81% to -34%), Serious injuries (ranging between -72% to -35%) and slight injuries (ranging between -58% to -25%) for children restrained appropriately in CRS.

Brubacher et al. (2016) investigated the effect of child restraint system use in samples of young children compared to an older control group as part of a study investigating the effects of restraint legislation. The overall study used an interrupted time series analysis to estimate the effect of the new law in terms of the injuries sustained. De-identified police reports for all motor vehicle crashes were used where they involved child passengers aged zero to 14. Data was drawn from the years 2000 to 2012 which covered the change in child seat laws. The study found that in line with the new law and better child seat use there was a 10.8% (95% CI 2.7% to 18.9%) reduction in the rate of injuries in four- to eight-year-old children compared to a control group of injury rates in children nine to 14 years of age. This reduction equates to a 13.0% decrease in the monthly injury rate among children zero to three years of age (95% CI 1.5% to 24.6%). The safety benefits observed in this study were mostly due to switching of children from inappropriate restraints such a standard three point seat belts into age-appropriate infant child restraint systems or booster seats.

Ma et al. (2012) looked at differences in protection an appropriately used child restraint provides for a range of age groups compared to inappropriate restraint use or no restraint use at all. The study used a cross-sectional approach to analyse data from the National Automotive Sampling Crashworthiness Data System, which collects together in-depth accident investigation on a sample of police reported motor vehicle collisions. The study grouped children into four age groups which coincided with child seat guidelines, these were: infants aged less than 1 year, toddlers aged 1 to 3 years, younger children aged 4 to 7 years, and older children aged 8 to 12 years. Data analysis compared the characteristics of the child passengers, drivers, vehicles and the crash among the three restraint groups for each age group of child with logistic regression models used to compare the odds of fatal and nonfatal injury among different restraint types. Results show that children with no restraint use experienced a significantly higher prevalence of fatal injury than children who were appropriately restrained for all age groups. This fatality rate was also significantly higher for inappropriately restrained children aged 1 to 3 years than for appropriate restraint use in this age group. Unrestrained children experienced odds 10 or more times greater for receiving a fatal injury during a motor vehicle collision compared with children who were appropriately restrained. Inappropriately restrained children aged 1 to 3 years had 6.28 times the odds of being fatally injured compared with those who were appropriately restrained after adjustment for potentially confounding factors.

Stewart et al. (2015) investigated the risk of head injury for infants seated in child restraint systems, particularly for those involved in higher speed crashes. Data was drawn from two datasets, the first included police records of all reported motor vehicle collisions from the Department of Transportation where data on child restraint systems and collision speeds were collected on infant passengers less than 1 year between 2007 and 2011.The second data set recorded data on the proper use of the car child restraint system, presence of traumatic brain injury and other injuries, and severity of injuries and was drawn from the Department of Public Health. In total 833 infants involved in motor vehicle crashes between 2007 and 2011 were included in the sample. Analysis of the sample confirmed that proper use of child restraint systems prevent injury to infants involved in motor vehicle crashes, more specifically by comparing the overall rates of properly restrained and improperly/unrestrained infants to the rates of injury and presentation to trauma centres of properly restrained and improperly/unrestrained infants, it is possible to show that properly restrained infants were 12.7 times less likely to be injured in an MVC and subsequently presented to a trauma centre.

Table 5 illustrates an overview of the main features and outcomes of the six coded studies.

Table 5: Main outcomes of coded studies on use of child restraint systems

Author, Year, Country	Exposure variable	Outcome variable / Outcome type	Effects		Main outcome –description
Høye, A.,2015, UK, USA, Netherlands (meta-analysis)	Child using a restraint	Fatal injury for unrestrained child	↘	81% reduction CL=95%, CI=0.92-0.57	Significant decrease in children receiving fatal injuries when restrained in a vehicle
		Severe injury for unrestrained child	↘	69% reduction CL=95%, CI=0.73-0.64	Significant decrease in children receiving severe injuries when restrained in a vehicle
		Injury for unrestrained child	↘	33% reduction CL=95%, CI=0.36-0.31	Significant decrease in children receiving an injury when restrained in a vehicle
		Minor injury for unrestrained child	↘	25% reduction CL=95%, CI=0.32-0.16	Significant decrease in children receiving a minor injury when restrained in a vehicle
	Child appropriately restrained	Fatal injury for unrestrained child	↘	59% reduction CL=95%, CI=0.65-0.51	Significant decrease in children receiving fatal injuries when appropriately restrained in a vehicle
		Injury for unrestrained child	↘	56% reduction CL=95%, CI=0.65-0.44	Significant decrease in children receiving an injury when appropriately restrained in a vehicle
		Severe injury for inappropriately restrained child aged 0 to 2	↘	43% reduction CL=95%, CI=0.55-0.29	Significant decrease in children ages 0 to 2 receiving severe injuries when appropriately restrained in a vehicle

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Author, Year, Country	Exposure variable	Outcome variable / Outcome type	Effects		Main outcome –description
		Fatal injury for inappropriately restrained child	↘	34% reduction CL=95%, CI=0.46-0.20	Significant decrease in children receiving fatal injuries when appropriately restrained in a vehicle
		Torso injury for inappropriately restrained child	↘	71% reduction CL=95%, CI=0.84-0.49	Significant decrease in children receiving a torso injury when appropriately restrained in a vehicle
		Severe or fatal injury for inappropriately restrained child aged 2 to 8	↘	35% reduction CL=95%, CI=0.39-0.29	Significant decrease in children ages 2 to 8 receiving severe or fatal injuries when appropriately restrained in a vehicle
		Severe injury for inappropriately restrained child	↘	72% reduction CL=95%, CI=0.86-0.43	Significant decrease in children receiving severe injuries when appropriately restrained in a vehicle
		Injury for inappropriately restrained child	↘	58% reduction CL=95%, CI=0.60-0.54	Significant decrease in children receiving an injury when appropriately restrained in a vehicle
Brubacher et al, 2016, Canada	Child restrained in standard belt	Injury for inappropriately restrained child aged 4 to 8	↘	10.8% reduction CL=95%, CI=0.027-0.18	Significant decrease in children aged 4 to 8 receiving an injury when appropriately restrained in a vehicle
		Injury for inappropriately restrained child aged 0 to 3	↘	13.0% reduction CL=95%, CI=0.015-0.24	Significant decrease in children aged 0 to 3 receiving an injury when appropriately restrained in a vehicle
Ma et al., 2012, USA	Appropriate restraint use for infant	Non-fatal injury for inappropriately restrained infant	-	OR 0.51 CL=95%, CI=0.15-1.78	Odds of an inappropriately restrained infant receiving non-fatal injuries in a motor vehicle collision show positive but non-statistically significant results
		Non-fatal injury for unrestrained infant	-	OR 3.91 CL=95%, CI=1.18-12.96	Odds of unrestrained infant receiving non-fatal injuries in a motor vehicle collision show negative but non-statistically significant results.
	Appropriate restraint use for toddler	Non-fatal injury for inappropriately restrained toddler	-	OR 1.25 CL=95%, CI=0.69-2.25	Odds of an inappropriately restrained toddler receiving non-fatal injuries in a motor vehicle collision show negative but non statistically significant results
		Non-fatal injury for unrestrained toddler	-	OR 6.65 CL=95%, CI=0.89-49.46	Odds of an unrestrained toddler receiving non-fatal injuries in a motor vehicle collision show negative but non statistically significant results
	Appropriate restraint use for young child	Non-fatal injury for inappropriately restrained young child	-	OR 0.51 CL=95%, CI=0.22-1.18	Odds of an inappropriately restrained young child receiving non-fatal injuries in a motor vehicle collision show positive but non statistically significant results
		Non-fatal injury for unrestrained young child	-	OR 1.25 CL=95%, CI=0.69-2.25	Odds of an unrestrained young child receiving non-fatal injuries in a motor vehicle collision show negative but non statistically significant results

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Author, Year, Country	Exposure variable	Outcome variable / Outcome type	Effects		Main outcome –description
	Appropriate restraint use for older child	Non-fatal injury for inappropriately restrained older child	-	OR 1.02 CL=95%, CI=0.49-2.15	Odds of an inappropriately restrained older child receiving non-fatal injuries in a motor vehicle collision show negative but non statistically significant results
		Non-fatal injury for unrestrained older child	↗	OR 2.97 CL=95%, CI=1.68-5.26	Odds of an unrestrained older child receiving non-fatal injuries in a motor vehicle collision show statistically significant negative results
	Appropriate restraint use for infant	Fatal injury for inappropriately restrained infant	-	OR 2.03 CL=95%, CI=0.19-21.47	Odds of an inappropriately restrained infant receiving fatal injuries in a motor vehicle collision show negative but non-statistically significant results
		Fatal injury for unrestrained infant	-	OR 23.79 CL=95%, CI=1.2-472.7	Odds of an unrestrained infant receiving fatal injuries in a motor vehicle collision show negative but non-statistically significant results
	Appropriate restraint use for toddler	Fatal injury for inappropriately restrained toddler	↗	OR 6.28 CL=95%, CI=2.4-16.4	Odds of an inappropriately restrained toddler receiving fatal injuries in a motor vehicle collision show statistically significant negative results
		Fatal injury for unrestrained toddler	↗	OR 21.11 CL=95%, CI=4.39-101.5	Odds of an unrestrained toddler receiving fatal injuries in a motor vehicle collision shows statistically significant negative results
	Appropriate restraint use for young child	Fatal injury for inappropriately restrained young child	-	OR 3.22 CL=95%, CI=0.56-18.72	Odds of an inappropriately restrained young child receiving fatal injuries in a motor vehicle collision show negative but non-statistically significant results
		Fatal injury for unrestrained young child	-	OR 16.24 CL=95%, CI=2.76-95.5	Odds of an unrestrained young child receiving fatal injuries in a motor vehicle collision show negative but non-statistically significant results
	Appropriate restraint use for older child	Fatal injury for inappropriately restrained older child	-	OR 2.15 CL=95%, CI=0.52-8.97	Odds of an inappropriately restrained older child receiving fatal injuries in a motor vehicle collision show negative but non-statistically significant results
		Fatal injury for unrestrained older child	-	OR 9.81 CL=95%, CI=2.05-46.9	Odds of an unrestrained older child receiving fatal injuries in a motor vehicle collision show negative but non-statistically significant results
Stewart et al., 2015, USA	Properly restrained infant	Admittance to trauma care for improperly restrained infant	↘	OR 12.7 CL=95%, CI=0.056-28.8	odds of a properly restrained infant presenting to a trauma centre with injuries after a motor vehicle collision is 12.7 times lower than that of an improperly/unrestrained infant

↗ = Significantly greater rates of injury to unrestrained child
↘ = Significantly less risk of injury to properly restrained child
- = Differences in injury rates may have been found, but not statistically significant or not known (i.e. statistical analysis not carried out).

METHODOLOGY

Literature Search strategy

Literature search was conducted in Jan 2017. Scopus database was browsed through during the literature search. Detailed search terms, as well as their linkage with logical operators and combined queries are shown in the following tables:

Database: Scopus **Search Date**: 24/01/2017

Search no.	Search terms / operators	Hits
#1	"Child Restraint System" OR "CRS" OR "Car seat" OR "child seat"	16,720
#2	"road safety" OR "crash" OR "traffic accident" OR "collision" OR "frontal crash" OR "side impact" OR "accident rate" OR "Road Casualties" OR "Road Fatalities"	352, 150
#3	"i-size" OR "isofix" OR "top tether" OR "rear facing"	494
#4	"ECE R94" OR "ECE R121" OR "E R129" OR "ECE R44.04" OR "ECE R44/04"	16
#5	"Performance" OR "effectiveness" OR "validation" OR "counter measure"	
#1 AND #2 OR #3 OR #4	>1990	346
#1 AND #2 OR #3 OR #4 AND #5	>1990	89

	CRS
Total number of studies to screen title/ abstract	435
-De-duplication	25
-Not relevant studies excluded	195
-Studies with no risk estimates excluded	135
Studies not clearly relevant to the topic (full-text screening later)	42
Remaining studies	38
Studies to obtain full-texts	18

- Prioritising Step A (most recent studies)
- Prioritising Step B (Journals over conferences and reports)

No meta-analyses were found.

3.1 REFERENCES

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