

Public health approaches to safer cycling for children based on developmental and physiological readiness: implications for practice

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ABSTRACT

Introduction Cyclists have a high mortality and morbidity per mile travelled compared with car occupants, a figure that is likely to increase if campaigns to increase active travel are successful. Concerns about safety is the leading factor limiting cycling for children.

Objective This review brings together a paediatric perspective based on the developmental readiness of children and young people and a public health approach to reducing injuries, to produce a practical agenda for improving the safety of cycling for children.

Method Selective literature review.

Results While most sports realise the importance of practice and training to create mastery of the game, similar thinking has not been consistently applied to cycling proficiency, so many children do not have an opportunity to master cycling before riding on the roads.

Conclusions The aim should be to minimise road traffic injuries involving children and young people in ways that create cobenefits for other members of society, increasing opportunities for active travel, reducing air pollution, creating more green space to play and reducing dependence on motor vehicles. Changes in legislation are required now to enable younger children to cycle on pavements while learning to ride and improvements in road design to separate cyclists from motor vehicles especially routes to school for older children.

INTRODUCTION

Cycling is currently being promoted as an active form of transport which has positive physical and mental benefits for health, contributes to a green economy by reducing air pollution and promotes a more sustainable planet in the longer term.¹

However, there is public concern about the safety of cycling on UK roads, highlighted by the recent deaths of adult cyclists in London.² A study from the European Transport Safety Council has shown that the UK ranked 23rd in making progress to reduce cycle deaths (in all ages) between 2003 and 2013 with an overall decline of less than 3%. This has come at a time when £23 million has been cut from

What is already known on this topic?

- ▶ Injury is a leading cause of mortality and morbidity in children and while motor vehicle injuries are reducing cycle injuries lag behind this trend.
- ▶ Injury prevention programmes require a multifaceted approach often involving multiple stakeholders and it is often difficult to prove their impact locally.
- ▶ Active travel is currently being promoted to improve mental health and reduce obesity, but may increase injuries if not accompanied by strategies to improve safety.

What this study hopes to add?

- ▶ This review combines a neurophysiological perspective to cycling readiness and a public health approach into practical recommendations to improve cycling safety.
- ▶ Improving safe routes to school—ideally separating vehicles from cyclists is a priority, especially for secondary school-age young people, combined with cycle training.
- ▶ Enabling younger children to legally ride on pavements and having parents behind cycling children if they are on the road would protect them from collisions with motor vehicles.

a budget of £114 million originally pledged to improve cycle safety.³

Children continue to be killed or seriously injured on roads throughout the UK, and while reducing road traffic accidents (RTA) involving adolescents has received considerable attention in recent years, injuries involving children and young people on bicycles have received less research attention and policy intervention. Anecdotal evidence from Child Death Overview Panels⁴ suggests there has been less reduction in these deaths than other forms of road traffic mortality.

This review brings together a paediatric perspective, based on evidence produced for



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Table 1 Police statistics cyclist casualties, 2014

	Child	Adult	All*
Killed	6	107	113
Seriously injured	273	3090	3401
Slightly injured	1726	15684	17773
Total	2005	18881	21287

*All includes casualties where age not recorded.

a recent review examining the developmental readiness of children and young people for cycling and a public health approach to reducing injuries to produce a practical agenda for improving the safety of cycling for children in the UK.^{5,6}

While written with cyclists in mind, many of the principles hold true for children and young people using electric bicycles, tricycles, scooters, motorcycles, quads and segways.

EPIDEMIOLOGY OF ROAD TRAFFIC INJURIES INVOLVING CHILDREN

In 2014, there were 1775 deaths on UK roads, 797 in cars, 446 pedestrians, 339 motorcyclists and 113 cyclists (see table 1). Of the cyclists, 107 were adults and six were children, and in addition 3090 adults and 273 children were seriously injured while cycling. For every 1 billion miles travelled 35 cyclists were killed compared with just two motorists. Cyclists are 23 times more likely to be involved in an RTA than motorists resulting in 6588 injured per billion miles travelled compared with just 286 in cars.

In the 72% of children killed or seriously injured on a school day the accidents generally occur between the hours of 08:00 and 10:00 or between 15:00 and 19:00. Data from Royal Society for Accident Prevention from 2015 showed that 69% were pedestrians, 14% were cyclists and 14% were travelling in cars. Children aged between 11 and 15 years accounted for the majority of childhood cycling casualties (52%) as at this age children start to travel to secondary school independently.⁷

A PAEDIATRIC PERSPECTIVE ON LEARNING TO CYCLE

Key points

Although the exact neurophysiological basis of growth and development throughout childhood is poorly understood, it is increasingly being investigated as new computer-based skill assessment methodologies and functional MRI become available.

While the majority of children can 'walk and talk' by 3 years of age, the milestone for riding a bicycle is very experience dependent, often being achieved around 5 years of age. However, physical mastery of the bicycle alone is insufficient to enable the safe riding on roads, where the child must interact with other motorised road users and constantly make decisions to enable them to remain safe.

This paper draws heavily on the 2014 review for the US National Highway Traffic Safety Administration entitled *Bicycle safety education for children from a developmental and learning perspective*⁸ and the paper submitted to the Transport and Industrial Relations Committee to lobby for a change in law to allow cycling on footpaths in New Zealand.⁹

In order to distil the literature/evidence into a structure which then links to interventions that could potentially reduce injuries, childhood development has been simplified and summarised into three chronological phases relevant to cycling—motor, visual and cognitive, but it must be recognised that development is a continuum and that cycling competence is highly dependent on practice. There will be exceptions with regard to chronology, for example, where children have not had access to a bicycle until an older age so they may know the Highway Code before attempting to balance on a bicycle.

Motor readiness: complex balancing and bicycle control skills

Riding a bicycle requires neurological integration of motor, sensory, visual and balance skills.¹⁰ Children initially concentrate on balancing while moving in a straight line. They will prioritise balance over decision-making as not falling off as their priority.¹¹ They go on to master steering, pedalling and braking and as their confidence builds they learn to start and stop and to cycle around small obstacles, demonstrating bicycle control. Developing these motor skills takes many hours of practice before the movements are efficient and fluent.

Initial training can be both indoors and outdoors, ideally on a firm surface. The use of helmets and protective gear is to be encouraged as slow speed falls are part of the learning process. It is essential that cycling skills are completely 'automatic' before moving on to road/traffic awareness.

Children should also learn the component parts of the bicycle and what they do. Later on, building on this knowledge, they learn how to assess the safety of the bicycle, for example, checking the brakes, tyres and seat height before cycling.

Visual sensory readiness: traffic awareness

Children find it difficult to integrate information from central vision which is essential for balance and peripheral vision which is required to detect traffic hazards. It is not unusual to see children stop pedalling and put their feet down when they are unable to simultaneously integrate information from two visual sources. Younger children are more likely to find it difficult to pay attention to more than one aspect of complex or potentially dangerous situations, such as when two cars are simultaneously approaching the point where the child is about to cross the road. Children perceive danger and react quite differently to adults—they often think that if they can see you, you can see them. They have little understanding of stopping distances, changing direction in a moving vehicle or the force of impact of being hit by a large vehicle.¹²

Before riding on the road, children require a knowledge of the 'rules of the road', which in the UK is encapsulated in the Highway Code. They must be able to recognise and respond to road traffic signs and be able to predict the movements of other vehicles based on their position, movement and indication, while appreciating the speed of other vehicles. They must be able to control their bicycle while performing hand signals (ie, be able to steer and brake with one hand). Their first experience of riding on the road should be in a 20 mph setting under the supervision of an adult.

Cognitive readiness: decision-making

Estimation of speed and distance is not a skill that reaches adult maturity until approximately 12 years of age (accepting this depends on exposure) and the execution of decisions, once made, is much slower in children than in adults.¹³ Response times do not reach adult levels until approximately 14 years of age.¹⁴

Risk-taking behaviours are common in adolescence. The prefrontal cortex which is essential for rational decision-making, inhibiting impulses, weighing up consequences and controlling self-regulation is the last part of the brain to develop and is usually only mature in the early 20s.^{15 16} Adolescence is also a time when peer group influence is at its maximum—which may be both hazardous (encouraging dangerous feats of bravado) or beneficial (when demonstrating compliance and competence).

For cycling on busy roads it is important to be able to ride safely in all weather and traffic conditions, both solo and in the company of other cyclists and be able to make important decisions in these challenging conditions.

Based on this physiological information it is clear that most children under the age of 14 are often not physiologically capable of riding safely on the road as they have not yet developed the necessary visual integration pathways, nor do they possess the cognitive competence. Under the age of 14 children should be encouraged to use cycle tracks or cycle lanes which are physically separated from motor vehicles. A change in legislation would allow children to ride on footpaths and pavements when cycle lanes are unavailable.

Before riding on the roads alone, supervised peer group rides in all traffic conditions, with time for reflection and learning, would be the ideal way of gaining the necessary practical experience. The use of virtual reality computer-based training, where different scenarios can be presented requiring the integration of multiple sensory inputs and appropriate decision-making, would appear to have potential in the future.

A PUBLIC HEALTH PERSPECTIVE: STRATEGIES TO AVOID OR MINIMISE RTAS

The injury epidemiology literature suggests that the most effective forms of intervention to prevent injuries are based around the principle of separating potential victims (cyclists) from potential hazards (motorised vehicles),

Table 2 Haddon Matrix with bicycle injury prevention examples

	Victim person	Agent vehicle	Environment factors
Preinjury	Cycle training adult supervision	Reducing numbers and speed	Improved visibility around school entrances
Injury	Helmet use	Separating vehicles and cyclists	Enabling children to cycle on footpaths
Postinjury	Access to first aid	Vehicle redesign	Access to health services

by creating an environment which physically distances them, such as independent cycle tracks, the creation of curbs and other physical barriers between cycle lanes and moving traffic. In addition, reducing road speeds and volumes of traffic are also important. Successful programmes often integrate multiple components such as safe routes to school¹⁷—walking buses, reduction in cars delivering children to school and local speed restriction enforcement.

Often there is a sequence of events leading up to an accident and resultant injury which, in retrospect, could have been altered, to prevent or ameliorate the injury. The Haddon Matrix is probably the most commonly used framework used in injury prevention. The matrix considers factors related to personal attributes, hazard attributes and environmental attributes; before, during and after an injury event. This framework, example below, can be used both to analyse injury events and then plan preventative programmes.

The matrix in [table 2](#) provides nine areas for potential intervention and the next steps to examine the evidence on the effectiveness of each intervention with regard to injury outcomes, prioritise based on local circumstances, implement the programme and then evaluate its effect.

The public health literature¹ then lists five stages to injury control:

- Identify the hazard (a hazard is anything that has the potential to cause harm) and includes activities, people, equipment, materials or the environment.
- Assess the exposure (exposure is the frequency of encountering the hazard).
- Assess the risk (risk is the probability of an injury as a result of contact with the hazard).
- Plan control measures (based on evidence of effectiveness).

¹Detels R, *et al.* Ed. Oxford Textbook of Public Health. Oxford Medical Publications.

E. Evaluate/monitor and feedback the impact of the prevention programme.

In practice, health education programmes which require whole populations to change their behaviour have been generally unsuccessful, whereas single long-lasting interventions, often backed by legislation, to modify the hazard (speed limits), enforce seat belt use or separate the victim from the hazard (cycleways/motorway barriers) have been more successful.

This approach is well established in industry,¹⁸ possibly because of potential compensation claims for employer negligence, but has not been systematically applied to the prevention of childhood injuries.

INTERVENTIONS TO IMPROVE SAFETY/REDUCE RISK FOR CHILDREN WHILE CYCLING IN THE UK

Based on the physiological and public health principles outlined above, the recommendations outlined below have the potential to improve the safety of children while cycling. As each nation in the UK is independent, some having implemented some of these recommendations already, so they are not presented a priority order. Each nation and local community should review their local provision and make plans accordingly.

Child-focused interventions

1. *Cycle training should be included within the school curriculum and the content of training should include physical control, traffic/road awareness and decision-making. Further research is required to determine the most effective programmes, duration and appropriate assessment methods.*

Cycling training programmes are often relatively short. The consensus is that it requires approximately 100 hours¹⁹ of training to develop a reasonable degree of cycle proficiency. Few cycling courses are longer than 10 hours and they often focus on knowledge and physical competency with relatively little focus on road-craft decision-making in real-life situations. Unsurprisingly, they may have little impact on reducing cycling injuries.^{20 21} However, longer training programmes have been associated with successful injury reduction.^{8 22} Current UK cycling proficiency awards have three levels of achievement, each stage building on previously achieved competencies.²³

If active transport is to become the normal form of transport for local journeys, it seems logical to provide all children with the necessary competence to ride a bicycle; so providing school-based training alongside other sporting activities would seem a practical strategy to achieve this aspiration.

The development of virtual reality computer programs, when linked to physical controls on a bicycle, could provide a realistic assessment of cycling competence akin to virtual reality pilot training.

2. *Helmet use should be encouraged, particularly in younger children, but further research is required to understand the*

properties of helmets required to prevent head injury when in contact with motor vehicles.

There is no law in the UK enforcing the wearing of helmets when cycling. The issue of compulsory wearing of helmets for all ages is complex. Standards are the same for adult and child helmets which are designed to protect wearers from falls to the ground on a flat surface, at under 12 mph.²⁴ The correct fitting of helmets is often problematic for both adults and children and the standards and testing of helmets vary widely across the world. Helmets are designed to protect the head from bicycle falls not to prevent brain injury following an impact with a motorised vehicle, which would require a design closer to current motorcycle helmets.²⁵

3. *When cycling on roads children less than 14 years of age should be accompanied by an adult, who cycles behind rather than in front of a child.*

It is difficult to define an age when children are competent to ride independently, particularly in a world with higher motor vehicle densities. Ideally this should be based on some form of competency assessment, but in the absence of formal rigorous assessment, adult supervision would appear to be the next best option. However, the adult should be able to observe the child at all times and cycle behind rather than in front as recommended by the Cycling Touring Club.²⁶

Vehicle-focused interventions

4. *Vehicle speeds on school routes should be reduced to less than 20 mph particularly at the beginning or end of the school day. Speed limits should be supplemented with physical structures that limit vehicle speed.*

Reducing the numbers of cars using roads close to schools and reducing their speeds at peak times when children are going to and from school is essential. Safe Routes to School programmes encourage walking and cycling and reduce reliance on motor vehicles to transport children to school. Variable speed limits that enforce lower speeds around routes to school, together with physical barriers such as speed bumps or lane restrictions, should be introduced particularly for secondary schools where children are transporting themselves independently.

Environment-focused interventions

5. *It should be legal for children up to 16 years of age and their parents/carers to cycle on pavements. (The same should be true for other vulnerable road users using bicycles.)*

Cycling on the footway (pavement) is an offence under Section 72 of the Highways Act 1835 as amended by Section 85 (1) of the Local Government Act 1888. Current road traffic legislation (in England) therefore prohibits the use of bicycles on pavements and footpaths.

The maximum fine for 'cycling on the pavement' is £500, but more usually enforced by a Fixed Penalty Notice which carries a fine of £50.00 if pleading guilty. However, children under the age of 10 are below the age of criminal responsibility and therefore cannot be prosecuted

and those under the age of 16 cannot be given a Fixed Penalty Notice.

In practice, while the law applies to all, the police can show discretion to younger children cycling on the pavement for whom cycling on the road would not be a safe option so it is unlikely that children up to the age of 16 will be prosecuted.

Enabling child cyclists to cycle on pavements has been achieved in Australia and Scotland. Because the numbers of cyclists are relatively small, concerns regarding perceived threats and conflicts with pedestrians have not materialised, although some pavement furniture and signage may require repositioning.²⁷

6. *Local authorities (or their equivalent) should review routes to school to enable more children to walk or cycle to school safely. Where possible, these routes ideally require physical separation between cyclists and motor vehicles.*

Cycling and walking to school are associated with higher levels of cardiovascular fitness and learning when compared with passive transportation to school and cycling encourages both skill acquisition and independence.^{28–30}

Adults cycling to school with their children also benefit. While cyclists should be safe when cycling in cycle lanes (lane marked out by painted lines within the carriageway) many motorists do not understand the marking system for cycle lanes, for example, if separated by a solid white line cars are prohibited from entering the cycle lane whereas interrupted white lines signal that the cars may enter if it is safe to do so. Investment in dedicated cycleways separate from traffic, or cycle lanes on widened footpaths in areas of high traffic density are the ideal option from a cycle safety perspective. While there appear to be no economic studies on the value of bicycle lanes in the UK, the benefits of a bicycle economy have been explored elsewhere³¹ together with the cycling contribution to the UK economy³² with future investment recommended.

CONCLUSIONS

Cyclists have a high mortality and morbidity per mile travelled compared with car occupants, a figure that is likely to increase if campaigns to increase active travel are successful. Although the greatest morbidity and mortality is in adults, prevention of injuries to children cyclists has, to date, not received the attention it should.

This paper highlights the need to understand the neurophysiological readiness and capability of children to ride safely on roads with other vehicles. The majority of children do not possess the competencies required until mid-adolescence and even then their cognitive capacity to make safe decisions depends on previous experience.

While most sports realise the importance of practice and training to create mastery of the game, similar thinking has not been applied to cycling proficiency, so many children are not given the opportunity to master cycling through regular training and supervision, before riding on the roads. This deficit could be rectified with

Box 1 Summary of recommendations

- ▶ Cycling should be considered a sport and cycle training included within the school curriculum.
- ▶ Helmet use should be encouraged, particularly in younger children.
- ▶ When cycling on roads children who are not yet competent should be accompanied by an adult, who cycles behind rather than in front of a child.
- ▶ Vehicle speeds on school routes should be reduced to less than 20 mph particularly at the beginning or end of the school day.
- ▶ It should be legal for children up to 16 years of age and their parents/carers to cycle on pavements.
- ▶ Local authorities (or their equivalent) should review routes to school to enable more children to walk or cycle to school safely. Where possible, these routes ideally require physical separation between cyclists and motor vehicles.

cycling being part of the educational curriculum and ethos of schools. The use of computer-assisted training should be explored for both training and assessment.

Given the temporal association of injuries coinciding with travel to and from schools it seems logical to develop safe routes to school as a priority, with pedestrian and cycle routes separated from traffic, or alternatively allowing children to cycle on pavements/footways as an intermediate action if dedicated cycleways cannot be created.

Six recommendations have been made (see **box 1**) that would seem to be both practical and appropriate.

In the longer term, the focus must be on reducing traffic volume and traffic speeds to protect children and vulnerable adults, in order to make communities safer places to live and travel.

Data on which to base decisions relating to cycle injuries and deaths in childhood are limited but there is potential both through Child Death Overview Panels and the development of emergency department surveillance systems, to further understand which of the attributable factors involved could be modified by future preventive strategies.

Our aim should be to minimise (to prevent the preventable) road traffic injuries involving children and young people in ways that create cobenefits for other members of society, increasing opportunities for active travel, reducing air pollution, creating more green space to play and reducing dependence on motor vehicles.

This paper presents six practical proposals based on neurophysiological readiness and sound public health principles to improve the lives and well-being of children while cycling.

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