THE FUTURE OF TRANSPORT

PUBLISHED PROJECT REPORT PPR920

Development of a New Cycle Helmet Assessment Programme (NCHAP)

Summary Report

P. Martin, V. StClair, A. Sutch, R. Khatry, S. O'Connell, D. Hynd

Report details

Report prepared for:	Road Safety Trust		
Project/customer reference:	RST 06/01/2016		
Copyright:	© TRL Limited		
Report date:	08/01/2018		
Report status/version:	v1.0		
Quality approval:			
Richard Oliver (Project Manager)	**12/10/2018**	David Hynd (Technical Reviewer)	**12/10/2018**

Disclaimer

Project Summary

Cycling is increasing in its popularity, with approximately 6.5 million adults cycling at least once a month in Great Britain [DfT 2017a]. Cyclists are a particularly vulnerable road user group; however, with 3,499 cyclists either killed or seriously injured and the second highest casualty rate in Great Britain during 2015 (3,327 casualties/billion vehicle km) [DfT 2017b]. With head and brain injuries associated with around one-third of cyclist hospital admissions and three-quarters of cyclist fatalities [Thompson *et al.* 2000; Macpherson and Spinks 2008; Olivier and Creighton 2016], the use of a helmet is an important risk management practice on the understanding that it provides additional protection to the wearer.

Whilst the impact safety performance of cycle helmets is fundamental to protecting cyclists during falls and collisions, no independent and freely available information is provided to consumers at the point of sale to support with assessing the relative safety performance of cycle helmet models. A key reason for this is a need to understand the fundamental science underpinning the development of advanced impact safety performance test and assessment protocols. Whilst protocols for evaluating cycle helmet safety performance have been well researched for linear impacts [Willinger *et al.* 2015], very little is known about the influence of other test variables, such as angled impacts, on the outcomes of the test.

This project therefore aimed to advance the state-of-the-art in the fundamental science that underpins advanced impact safety performance testing and assessment protocols for cycle helmets. Furthermore, the project aimed to develop draft testing and assessment protocols for a future New Cycle Helmet Assessment Programme (NCHAP).

To achieve the aims of this project, a short literature review was performed first to identify key topics for focussing the research. On the basis of this review, the project was split into six key work packages, with these consisting of four experimental studies, one international cycle helmet safety workshop and one desk-based work package to draft the New Cycle Helmet Assessment Programme (NCHAP) protocols. This report provides an introduction to, summary of and conclusions from the six work packages performed during this project.

The impact performance of cycle helmets during high energy linear impacts against both flat and kerbstone anvils was characterised, alongside the safety performance of cycle helmets during linear compound impacts (where the helmet is impacted multiple times at the same point). Oblique impacts, performed at an angle to the helmet to introduce a rotational force, were investigated, with the effects of both the angle of the anvil and the headform used during testing established. Finally, the repeatability of the test and assessment approach was then analysed to determine the suitability of the approach for the NCHAP scheme.

After facilitating a Workshop to consult with global experts on harmonising the cycle helmet safety testing and assessment approaches, draft protocols were then developed for the future NCHAP scheme based on the outcomes of this research. Whilst the proposed NCHAP test and assessment protocols applied current best practices, research gaps were identified by this report. These gaps included topics requiring further research before finalising the current NCHAP protocols and topics requiring further research to progress future advances to the NCHAP protocols.

Table of Contents

1 Introduction

1.1 Project Background

Cycling is increasing in its popularity, both as a mode of transport and as a recreational activity, with approximately 6.5 million adults across Great Britain (GB) cycling at least once a month and travelling an estimated 5.6 billion vehicle kilometres (bvkm) on the road [DfT 2016; DfT 2017a]. Cyclists are a particularly vulnerable road user (VRU) group, however, with a casualty rate of 3,327 casualties per bvkm; the second highest rate in GB [DfT 2017b]. In total, 3,499 cyclists were either killed or seriously injured in GB during 2015 [DfT 2017b].

Traumatic brain injuries pose the greatest risk of fatal and serious injuries to cyclists and are associated with around one-third of cyclist hospital admissions and three-quarters of cyclist fatalities [Thompson *et al.* 2000; Macpherson and Spinks 2008; Olivier and Creighton 2016]. The use of helmets when cycling is primarily a risk management practice that intends to provide additional protection to the wearer in the event of a fall or if struck by an object. The principal purpose of a cycle helmet is therefore to protect the head from impacts by absorbing energies that would otherwise impart large forces and accelerations to the head and cause injury [Hynd *et al.* 2009]. Current cycle helmet designs attempt to achieve this by combining a number of different approaches, including; distributing the forces over a larger area (to reduce skull fracture risk) and minimising the linear and rotational accelerations of the head (to reduce brain injury risks).

Despite being a critical item of personal protective equipment, the safety performance of cycle helmets have been found to vary considerably between models [Stigson and Kullgren 2015; DeMarco *et al.* 2016; Stigson 2017]. Although cycle helmet safety performance is fundamental to the protection of cyclists during a fall or collision, no independent and freely available information is provided to consumers at the point of sale to support them with assessing the relative safety performance of cycle helmet models. This is in stark contrast to motorcycle helmets, where safety performance ratings are provided to consumers through the SHARP helmet testing and assessment protocols [Delmonte *et al.* 2015].

One key reason for this paucity of information is the need to understand the fundamental science underpinning the development of advanced impact safety performance testing and assessment protocols for cycle helmets. Whilst cycle helmet impact safety performance has been well researched for linear impacts [Willinger *et al.* 2015], very little is known about the variation in the safety performance of cycle helmets when investigating the influence of other testing and assessment variables. As there are a large number of variables involved in the development of future testing protocols, it is important to ensure that the current best practices for testing and assessing safety performance are implemented wherever possible.

1.2 Project Aims

This project therefore aimed to advance the state-of-the-art in the fundamental science that underpins advanced impact safety performance testing and assessment protocols for cycle helmets. The project further aimed to develop draft testing and assessment protocols for a future New Cycle Helmet Assessment Programme (NCHAP).

1.3 Project Approach and Reporting Structure

To achieve the aims of this project, a short literature review was first performed to identify the key areas for focussing the research. On the basis of this review, the project was split into six key work packages (WPs), with these consisting of four experimental studies, one international cycle helmet safety workshop and one desk-based work package to draft the New Cycle Helmet Assessment Programme (NCHAP) testing and assessment protocols.

The report provides an introduction to, summary of and conclusions from the work packages performed during this project. The report first provides an overview of the project background, aims and approach in the Introduction, before following this with a section to summarise the literature review and six stand-alone sections for each of the work packages. Finally, the Future Research Requirements and Project Conclusions sections summarise the outcomes and conclusions of the project and its future research recommendations.

2 Literature Review Summary

The literature review focused on three key research themes that underpin the design of high quality evidence-based helmet safety performance testing and assessment protocols. These included an analysis of literature describing the characteristics of real-world cyclist collisions, a comparison and critical review of current international cycle helmet testing standards and a review of the state-of-the-art in traumatic brain injury risk criteria. These outcomes were then used to inform the initial development of the NCHAP testing and assessment protocols.

The cyclist accidentology review analysed a range of research literature, collision databases and cycling ridership statistics to quantify the key characteristics of cyclist collisions. The key demographics of cyclist casualties were defined to quantify age, gender, height and weight. Helmets were observed to be impacted at any location during a collision; however, impacts were typically concentrated around the maximum circumference of the helmet (comprising of the parietal region and the helmet edges in the frontal and temporal regions). Similarly, helmets were found to be impacted at any impact angle; however, approximately 89% of impacts occurred between angles of 0-60° from normal. Principle causes of cyclist collisions include motorised vehicle and single-vehicle collisions (i.e. falls), with rates again varying significantly between studies. Cyclist speeds prior to collisions ranged from 2-25 kph (mean: 12 kph) across all collision causes, with vehicle speeds ranging between 7.5-70 kph (mean: 41 kph) for motor vehicle collisions only. Finally, when involved in a collision, helmets were found to reduce cyclist head injury risks by 31-78% across a range of studies.

The critical appraisal of current cycle helmet testing and assessment standards reviewed and compared a total of seven standards currently in force across the world. These included national helmet certification standards from Europe, USA, Canada, Japan, Australia and New Zealand, as well as one globally implemented standard (Snell B-95). The critical appraisal of these standards focussed on summarising and comparing differences between the various testing and assessment approaches adopted by each standard for the key characteristics associated with each safety performance requirement. These include headform types, drop test assemblies, neckform anchorages, anvils, helmet coverage, specified impact locations, environmental preconditioning, impact energies, pass/fail criteria and the number of tests required for cycle helmet impact performance requirements. The characteristics of helmet retention, stability and field of vision tests were also critically appraised, whilst the different approaches taken by each standard towards certification were also discussed. Based on this appraisal, this review proposed a number of recommendations to further inform the initial development of the NCHAP testing and assessment protocols.

The final literature review section provides a detailed overview of the theory underpinning the head injury continuum, before summarising the state-of-the-art in head injury criteria. It provides an overview of each head injury criterion, before identifying the relevant injury risk thresholds associated with each criterion. These criteria were first categorised into five key classifications, which include localised loads skull fracture criteria, translational head injury criteria, rotational head injury criteria, combined translational and rotational head injury criteria and brain tissue stress and strain criteria. Covering over 20 head injury criteria and over 200 associated injury risk thresholds, this state-of-the-art review of head injury criteria provides a complete overview of all relevant injury criteria and risk thresholds that may be utilised by the NCHAP protocols.

Further information on the Literature Review and its recommendations, may be found in the published report entitled "*New Cycle Helmet Assessment Programme (NCHAP) Literature Review*". It should be noted that this literature review was completed in 2017 to inform the initial development of the NCHAP protocols, so includes articles published prior to 2017 only.

3 WP1: Linear and Compound Impacts

3.1 Work Package Approach

This work package aimed to ***quantify the effects of impact energy and compound impacts, for both flat and kerbstone impact anvil designs, on head injury risks for a single helmet model***. Wire-guided linear drop tests, following CPSC – 16 CFR Part 1203 protocols, were performed to assess the effects of impact energy and compound impacts on head injury risk. Helmets were securely mounted to EN 960:2006 specified three-quarter headforms, before impacting EN 1078:2012+A1:2012 specified flat and kerbstone shaped anvils at predefined impact locations within the left and right temporal regions of the cycle helmet (Figure 1). Only one helmet was model was selected for use in this study (Trax Mistral Bike Helmet).

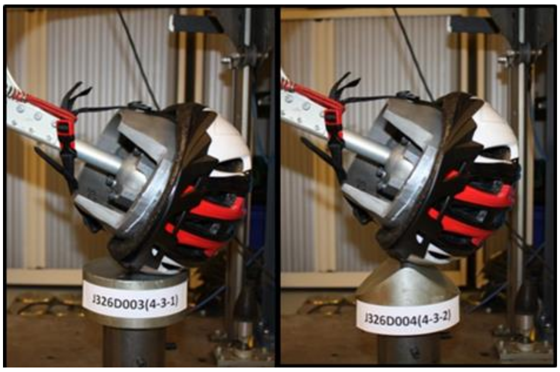

Figure 1: Wire-guided linear headform drop test set-up impacting the right temporal region on the flat and kerbstone anvils

Two consecutive drop tests of each helmet were performed for each impact location. The first test was performed across a range of heights ranging from 1-3 m in 0.5 m increments, whilst the second test was performed from a height of 1 m only. Helmets were dropped on to either a flat or a kerbstone anvil based upon testing requirements. Various metrics were recorded for each helmet impact and compared to a range of current state-of-the-art head injury criteria; here outcomes are presented for peak linear accelerations only.

3.2 Work Package Outcomes

Impact energies, impact partner shapes and compound impacts were all shown to affect the safety performance of cycle helmets (Figure 2). Higher impact energies were observed to result in greater peak linear headform accelerations. Although a considerable increase in headform accelerations was caused by the kerbstone anvil for drop heights of 2.5 m or greater, high energy impacts onto the flat anvil only exceeded legislative safety performance criteria when impacted from a 3.0 m drop height (when compared to drop heights of 1.5 m in current test standards). Compound impacts were primarily affected by the proportion of undamaged EPS material engaged by the compound impact.

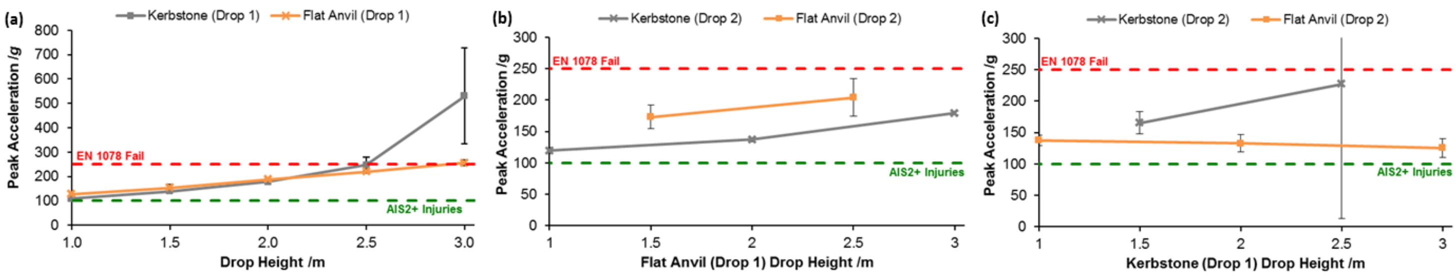

Figure 2: Mean peak linear headform accelerations for (a) the first impact (Drop 1) against both the flat and kerbstone anvils and the compound impact (Drop 2) against both the flat and kerbstone anvils when compared to the drop height of the first impact (Drop 1) against the (b) flat and (c) kerbstone anvils

It was therefore recommended that advanced testing protocols should recognise and assess the relative safety performance of cycle helmets against these various variables.

4 WP2: Influence of Anvil Angle

4.1 Work Package Approach

This work package aimed to ***quantify the effects of impact anvil angle across a range of cycle helmet models and establish the repeatability of the oblique impact testing approach***. Free fall drop carriage tests, which adapted EN 1078:2012+A1:2012 protocols to perform oblique impact tests, evaluated the effects of anvil angle on head injury risk. Helmets were securely mounted to a full sized EN 960:2006 specified headform, before being positioned on a modified “horseshoe” drop carriage design to ensure the left temporal region of the helmet was impacted. Four different helmet models were selected for this study:

- Model 1: Trax Mistral Bike Helmet
- Model 2a: Bell Draft MIPS Helmet 2016
- Model 2b: Bell Draft MIPS Helmet 2016 – with MIPS structure removed
- Model 3: Mongoose Urban Helmets

Drop tests were performed by impacting helmeted headforms against a flat steel angled anvil, with fresh 80 gsm sandpaper attached securely to the anvil face for each test. A range of anvil angles was investigated in 5° increments between 30-60° to the horizontal, with impact velocities calculated specifically for each anvil angle to represent collisions occurring at different cyclist speeds. Outcomes are presented for peak linear accelerations, rotational velocities and rotational accelerations and compared to a range of head injury criteria. To assess repeatability, 20 additional helmet drop tests (five repeat helmet drop tests for each helmet model) were also performed using a 45° anvil angle with a 3 m drop height.

4.2 Work Package Outcomes

Differences seemed to exist in cycle helmet performance when impacted at different anvil angles, with different helmet models seeming to respond differently to different anvil angles (Figure 3). No specific angle, however, seemed to consistently provide a "worst-case" angle across all helmet models tested. An anvil angle of 45° to the horizontal and impacted from a drop height of 3 m was, however, perhaps the most appropriate combination to use as peak values for the rotational velocities and accelerations seemed to be located approximately at this point. Furthermore, this combination represented a cyclist fall occurring whilst cycling at 20 km/h, which is approximately the average speed for a cyclist [Boufous *et al.* 2018].

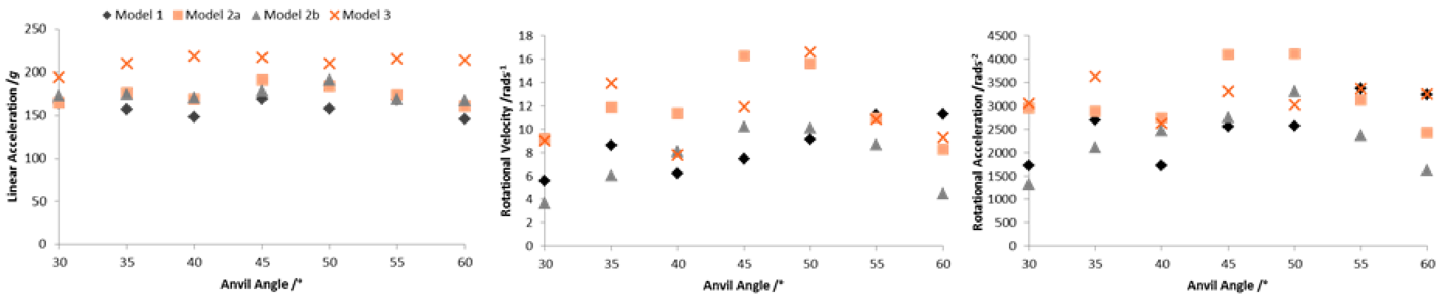

Figure 3: Peak (a) linear accelerations, (b) rotational velocities and (c) rotational accelerations experienced by four different helmet models when impacted against a range of different anvil angles

Differentiation between the oblique safety performances of the helmet models, particularly for the rotational headform velocities and accelerations, was unachievable due to the poor repeatability of the oblique impact test methods adopted (Figure 4). This was a key outcome of this study and identified a necessity to highly control several of the key testing variables. These key variables included impact location, strength of the helmeted headform anchorage, helmet position on the headform and adequate adjustment of the retention system.

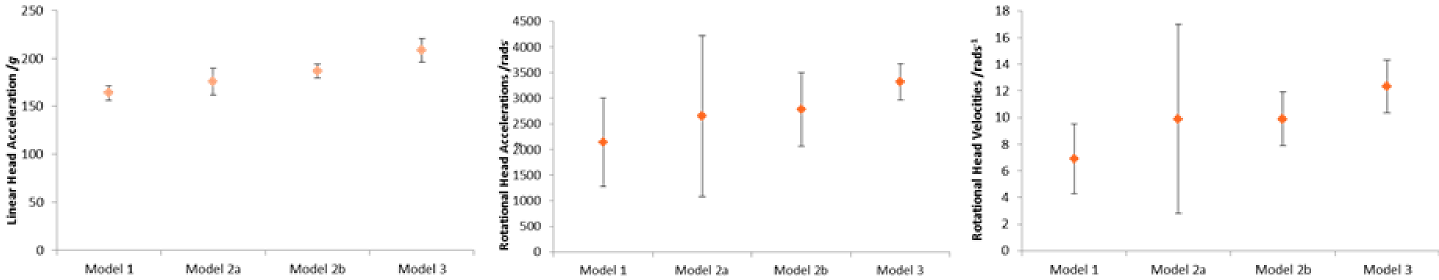

Figure 4: Repeatability of oblique impact tests for four different helmet models

With these lessons learnt, the repeatability of the oblique impact testing and assessment approach was improved for the following work packages.

5 WP3: Headform Type and Impact Location

5.1 Work Package Approach

This work package aimed to ***quantify the differences in the kinematics of the head between the EN 960:2006 and Hybrid III headforms*** during oblique cycle helmet impacts. Using an updated approach, based on the lessons learnt from WP2, a free fall drop carriage test was performed by impacting helmeted headforms against an angled anvil to assess head injury risk. Helmeted headform drop tests used either a full sized, EN 960:2006 compliant, 575 mm circumference magnesium headform (4.82 kg) or 50th percentile Hybrid III headform (4.54 kg). Two different helmet models were selected for use in this study:

- Model 1: Trax Mistral Bike Helmet
- Model 2a: Bell Draft MIPS Helmet 2016

Helmets were securely mounted to the specified headform, before being positioned on the modified “horseshoe” drop carriage to impact the helmeted headform across four different specified helmet impact locations including: the crown, frontal, occipital and left temporal regions. Each helmeted headform was dropped from a height of 3 m onto a flat steel anvil angled at 45° to the horizontal plane, with fresh 80 gsm sandpaper attached securely to the anvil face. Each helmeted headform was impacted once, with three repeat tests performed for each helmet model, impact location and headform.

Outcomes were calculated for peak linear accelerations, rotational velocities and rotational accelerations and compared to a range of head injury criteria. Mean differences in safety performance between the headforms used were compared to evaluate the influence of the headform on each outcome.

5.2 Work Package Outcomes

Mean peak linear accelerations, rotational velocities and rotational accelerations recorded for each helmet model, headform and impact location are illustrated against alongside key legislative performance criteria and published head injury criteria thresholds in Figure 5.

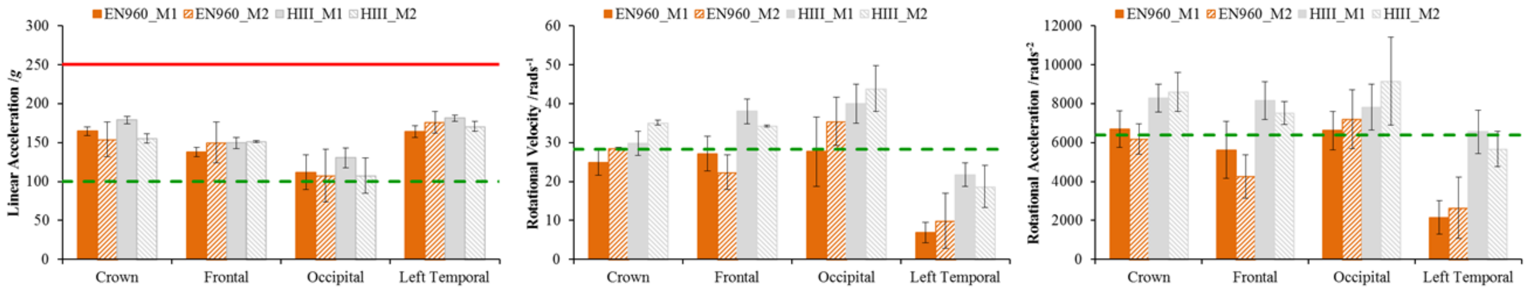

Figure 5: Mean peak (a) linear accelerations, (b) rotational velocities and (c) rotational accelerations experienced by the EN 960:2006 (EN960) and Hybrid III (HIII) headforms when testing two different helmet models (M1, M2) at four different impact locations

Although no legislative performance criteria were exceeded, at least one AIS2+ head injury criterion was exceeded during each oblique impact test. The 100 g AIS2+ linear acceleration injury criterion was exceeded during all but one impact test, whilst 48% of helmet drop tests exceeded the 28.3 rads^{-1} AIS2+ rotational velocity injury threshold and 54% exceeded the 6,383 rads^{-2} AIS2+ rotational acceleration injury threshold.

A significant increase in rotational velocities and accelerations for the Hybrid III headform was found when compared to the EN 960 headform, regardless of the helmet model used and impact location. A significant increase in linear headform accelerations was observed across all impact locations for Model 1 only, whilst no significant difference was observed for Model 2. Given these differences, and the consensus expert opinion that the Hybrid III headform is more biofidelic in its design, it was recommended that future advanced cycle helmet testing protocols consider the use of the Hybrid III range as the test headform.

6 WP4: Testing Repeatability and Performance Differentiation

6.1 Work Package Approach

This work package aimed to ***explore the repeatability of the oblique impact testing protocols*** and establish, by simulating an idealised helmet slip plane, whether these protocols may be used to ***differentiate between the rotational impact safety performances of different cycle helmet models***. In order to simulate the idealised helmet slip plane, the 80 gsm sandpaper (which would normally be securely attached to the anvil face) was strategically cut to leave ≤5 mm of material supporting its attachment to the anvil. This work package then compared the differences in outcomes between tests performed with the idealised slip plane and with the sandpaper securely attached to the anvil face.

Free fall drop carriage tests were performed by impacting helmeted headforms against a 45° angled anvil from a drop height of 3 m to assess head injury risk. Helmeted headform drop tests used a 50th percentile Hybrid III headform (4.54 kg), whilst only one helmet model was selected for use in this study (Trax Mistral Bike Helmet). Helmets were securely mounted to the specified headform, before being positioned on the modified “horseshoe” drop carriage to impact the helmeted headform across four different specified helmet impact locations including: the crown, frontal, occipital and left temporal regions. Each helmeted headform was impacted once, with five repeat tests performed at each impact location and for each experimental slip plane case.

Outcomes were calculated for peak linear accelerations, rotational velocities and rotational accelerations and compared to a range of head injury criteria. Mean differences in safety performance between the “no slip” (i.e. fixed 80 gsm sandpaper) and the idealised slip plane cases were compared to evaluate whether the proposed oblique impact safety performance protocol will be able to establish any difference in performance between helmet models.

6.2 Work Package Outcomes

The repeatability of the final procedure across the five repeat tests for each impact location and slip plane case was found to be acceptable. Linear accelerations were found to have a ~3% coefficient of variation (CoV), rotational accelerations had a ~10% CoV and rotational velocities had a ~10% CoV. The “no slip” helmeted headform drop tests experienced greater rotational velocities across all impact points and greater rotational accelerations for the frontal, occipital and temporal regions (Figure 6). For linear accelerations only, the temporal region experienced any differences in peak linear acceleration.

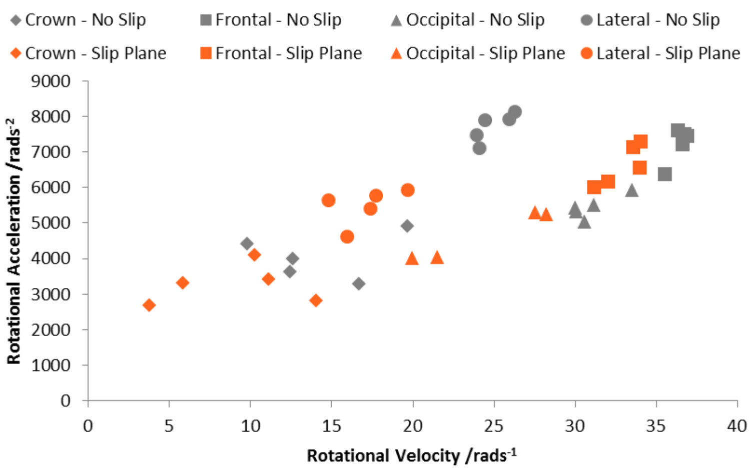

Figure 6: Comparison of rotational velocity and rotational accelerations for each impact location and each slip plane case

When considering differentiating between the oblique impact safety performances of the two slip plane cases, it is clear to see that impact safety performance was more sensitive to helmet impact location than differences in helmet design. When oblique impact safety performance is compared at equivalent impact test locations, however, it is clear that safety performance may be differentiated between the two slip plane cases. This difference, although distinct, remains only marginal for certain impact locations (e.g. frontal), whilst is much larger for other impact locations (e.g. lateral). This implies that, should the idealised slip plane assumption of the “slip plane” cases hold true, there may be very little real-world benefit to be gained by introducing a slip-plane at the impact locations with a marginal difference in safety performance. This outcome does, however, direct future advanced cycle helmet test and assessment protocols towards ensuring that multiple impact locations are assessed. It is important to explore whether these outcomes are transferrable between other models and especially those that claim improved performance during oblique impacts.

7 WP5: International Cycle Helmet Safety Workshop

During the course of this project, several research institutes begun to develop cycle helmet test and assessment programs to rate the relative safety performance of cycle helmets. These institutes are truly international, with the UK, US, Sweden, Germany and France all beginning to develop such programs. To maximise the positive impact of this approach, it was the opinion of the project team that the global harmonisation of these approaches at an early stage may be beneficial.

The project team therefore arranged a Cycle Helmet Safety Workshop to bring together the leading global experts at the 6th annual International Cycling Safety Conference (2017). The Cycle Helmet Safety Workshop aimed to provide an opportunity for these global experts to present the latest outcomes of their research, discuss current best practices for testing and assessing cycle helmet safety performance, and provide a forum for debating the global harmonisation of the various approaches currently being researched across the World.

The Workshop comprised of three presentation sessions followed by an interactive session. The first presentation session focused on challenges facing the current cycle helmet testing landscape and the requirements for ensuring rating schemes remain focused on consumer needs. The second session focused on global approaches toward testing cycle helmet safety performance, with presenters commenting on current best practices used by each research institute and the effects of these approaches on outcomes. The third presentation session focussed on the global approaches toward assessing cycle helmet safety performance and centred on the current assessment philosophies adopted by each research institute.

Finally, the interactive Workshop session aimed to develop a three-year plan for achieving an evidence-based, successful and sustainable cycle helmet safety consumer information rating scheme and provided a platform for discussion on the various benefits/disbenefits surrounding the key issues for global harmonisation (Figure 7, overleaf). A group discussion activity was first used to generate a wall chart that illustrated a vision for what a successful scheme may look like in three years' time. Roadmaps were then created that described the current state-of-the-art, the three-year vision for a global cycle helmet rating scheme and the steps that would need to be implemented to ensure this three-year vision is achieved.

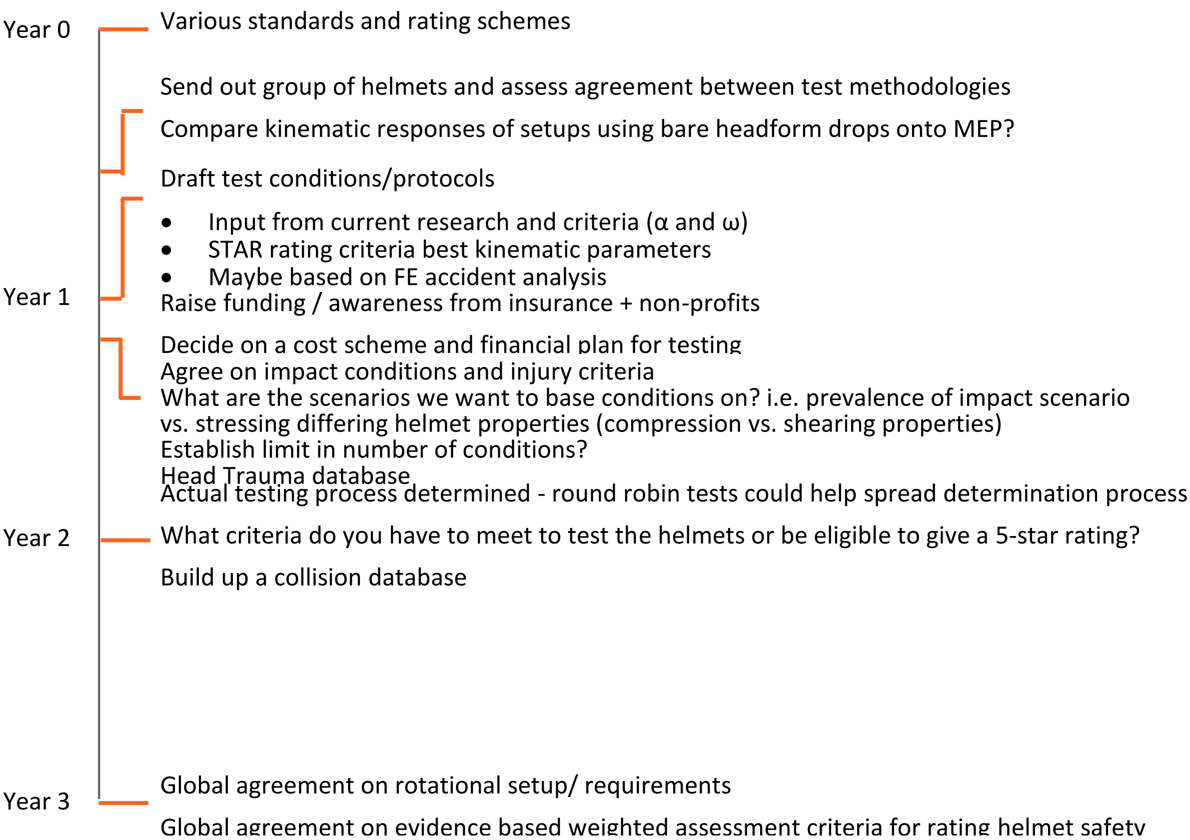

Figure 7: Three-year timeline for the roadmap to a globally harmonised cycle helmet safety testing and assessment protocol

Further information on the Workshop, its outcomes and recommendations, may be found in the published Workshop report entitled "*International Cycling Safety Conference 2017: Cycle Helmet Safety Workshop Report*".

8 WP6: Developing the NCHAP Protocols

Two separate testing protocols for the New Cycle Helmet Assessment Programme (NCHAP) were drafted based on the recommendations of the previous Work Packages. These were linear impact testing protocols, which comprises of both high energy and compound linear impact tests, and oblique impact testing protocols, which comprises of oblique impact tests against angled anvils.

9 Future Research Requirements

Although this project makes significant progress towards advancing the state-of-the-art in advanced cycle helmet impact safety performance test and assessment protocols, a number of topics still require further research. These can be split into two key sections: topics that require further research before finalising the linear and oblique impact test protocols; and topics that require further research to develop future NCHAP protocols.

When considering the current linear and oblique NCHAP test protocols proposed within WP6 of this project, further research is required prior to being able to finalise the protocols and make them publicly available. Firstly, and perhaps most importantly, a case-by-case investigation into cyclist collisions and falls may be required to reconstruct the cases and better understand the magnitude and angle of impact forces experienced by cycle helmets during typical impact scenarios. This may be used to prioritise the test points and headform orientations for use in the NCHAP testing protocols. It is also important to better establish the influence of both the impact angle and drop height during oblique impact tests. As the repeatability of the WP2 testing methods were improved on in subsequent work packages, an improved analysis, that significantly reduces the variation between results, may now be performed to more robustly understand the effects of the impact angle and drop height on outcomes. This should also be performed with a more representative sample of helmets, as this research was limited to the testing of four different helmet models, based principally on design functionality (BMX-style hard shell helmet, soft shell cycle helmet, multi-directional Impact Protection System (MIPS) helmet and MIPS helmet with MIPS component removed). Finally, the reproducibility of proposed test and assessment protocols between laboratories should also be established to optimise the reproducibility of the protocols.

Future research is also required for the development of new NCHAP test and assessment protocols. This research can be split into key topics that aim to develop the impact testing, comfort testing and safety performance assessment aspects of the rating scheme. Impact safety performance test protocols may be developed to assess retention system strength and stability, high/low energy oblique impacts and helmet coverage area and performance. Furthermore, the influence of different neck forms during impact also requires investigation. Comfort rating test protocols may also be developed to evaluate the fit, field of view, mass, visor fogging, waterproof, acoustic emission, aerodynamic and ventilation performance of cycle helmets. Finally, it is important to establish the benefits of using finite element analysis (FEA) approaches to determine head injury risk for use in the assessment protocols. This will remove the need to derive separate injury criteria for the linear and oblique impact testing protocols and promote the use of a combined cycle helmet safety performance criterion.

10 Project Conclusions

This project has contributed to advancing the state-of-the-art in the testing and assessment of cycle helmet impact safety performance. The impact performance of cycle helmets during higher energy linear impacts against flat and kerbstone anvils were characterised, alongside the safety performance of cycle helmets during linear compound impacts. Oblique impacts to the helmet were also investigated, with the effects on the outcomes of both the angle of the anvil and the headforms used during testing established. The repeatability of the impact safety performance testing and assessment protocols was then analysed to evaluate the suitability of these protocols for the New Cycle Helmet Assessment Programme (NCHAP). Finally, after facilitating a Workshop to consult with global experts on the harmonisation of cycle helmet safety testing and assessment approaches, draft protocols were developed for the future NCHAP scheme based on the outcomes of this research. Whilst the proposed NCHAP test and assessment protocols apply the current best practices, further research areas were identified by this report. These included topics requiring further research before finalising the current NCHAP protocols and topics that require further research to progress future NCHAP protocols.

11 References

Boufous S, Hatfield J and Grzebieta R (2018). *The impact of environmental factors on cycling speed on shared paths.* Accident Analysis & Prevention 110. 171-6.

Delmonte E, Martin P, Helman S, Hynd D, FernÃ¡ndez-Medina K and Kinnear N (2015). *SHARP: A Study of Its Effect on the UK Motorcycle Helmet Market.* PPR747.

DeMarco AL, Chimich DD, Gardiner JC and Siegmund GP (2016). *The impact response of traditional and BMX-style bicycle helmets at different impact severities.* Accident Analysis & Prevention 92. 175-83.

DfT (2016). *Local Area Walking and Cycling Statistics: England, 2014/15.* Department for Transport (DfT).

DfT (2017a). *Road Traffic Estimates: Great Britain 2016.* Department for Transport (DfT).

DfT (2017b). *Reported road casualties in Great Britain: 2016 annual report.* Department for Transport (DfT).

Hynd D, Cuerden R, Reid S and Adams S (2009). *The Potential for Cycle Helmets to Prevent Injury a Review of the Evidence, London.* Transport Research Laboratory, Published Project Report PPR 446.

Macpherson A and Spinks A (2008). *Cochrane review: Bicycle helmet legislation for the uptake of helmet use and prevention of head injuries.* Evidence Based Child Health: A Cochrane Review Journal 3(1). 16-32.

Olivier J and Creighton P (2016). *Bicycle injuries and helmet use: a systematic review and meta-analysis.* International journal of epidemiology 46(1). 278-92.

Stigson H and Kullgren A (2015). *Folksam's Bicycle Helmet Test 2015.*

Stigson H (2017). *Bicycle Helmets 2017 Tested by Folksam.* Stokholm: Folksam.

Thompson DC, Rivara FP and Thompson R (2000). *Helmets for preventing head and facial injuries in bicyclists.* Nursing times 97(43). 41-.

Willinger R, Halldin P, Bogerd C, Deck C and Fahlstedt M (2015). *Final report of Working Group 3: Impact engineering. A COST Action TU1101/HOPE collaboration.*

Development of a New Cycle Helmet Assessment Programme (NCHAP)

This summary report provides an introduction to, summary of and conclusions from the work packages performed during the "Development of a New Cycle Helmet Assessment Programme (NCHAP)" project. This project aimed to advance the state-of-the-art in the fundamental science that underpins advanced impact safety performance testing and assessment protocols for cycle helmets. The project further aimed to develop draft testing and assessment protocols for a future New Cycle Helmet Assessment Programme (NCHAP).

The report first provides an overview of the project background, aims and approach in the Introduction, before following this with a section to summarise the literature review and six stand-alone sections for each of the work packages. These six key work packages consisted of four experimental studies, one international cycle helmet safety workshop and one desk-based work package to draft the New Cycle Helmet Assessment Programme (NCHAP) testing and assessment protocols. Finally, the Future Research Requirements and Project Conclusions sections summarised the outcomes and conclusions of the project and its future research recommendations.

PPR921	International Cycling Safety Conference 2017: Cycle Helmet Workshop Report. Cycle helmet safety: Global harmonisation of consumer information rating schemes. P. Martin, S. O'Connell, D. Hynd. 2019
PPR922	Development of a New Cycle Helmet Assessment Programme (NCHAP) Literature Review. P. Martin, S. O'Connell. 2019
PPR759	Safety Testing of Helmet-Mounted Cameras. P. Martin, V. StClair, C. Willis. 2015
PPR446	The Potential for Cycle Helmets to Prevent Injury: A Review of the Evidence. D. Hynd, R. Cuerden, S. Reid, S. Adams. 2009

TRL
Crowthorne House, Nine Mile Ride,
Wokingham, Berkshire, RG40 3GA,
United Kingdom
T: +44 (0) 1344 773131
F: +44 (0) 1344 770356
E: enquiries@trl.co.uk
W: www.trl.co.uk

ISSN 2514-9652

ISBN 978-1-913246-04-4

PPR920