Comments on Depreitere et al. Lateral Head Impacts and Protection of the Temporal Area by Bicycle Safety Helmets’

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Nigel J Mills, Ph D

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From the University of Birmingham, Birmingham, United Kingdom,

The side of the head is vulnerable to trauma in bicycle accidents. Depreitere et al demonstrated contact between a flat-faced pendulum, and the side of cadaver heads, when bicycle helmets were worn. Computer design methods were used to interpret these experiments, showing that typical helmets safely absorbed 75% of the impact kinetic energy before pendulum-to-head contact occurred. Furthermore, in typical oblique impacts with the road, two factors improve the head protection. The tangential velocity component slightly improves the helmet performance, while prior shoulder impact on the road decreases the head impact velocity. It is concluded that current helmets provide adequate protection for typical lateral head impacts.

Depreitere et al.,1 discussed the evolution of bicycle helmets since the 1970’s. They pointed out that the temporal area is only partially covered by a helmet, despite it being vulnerable. They performed experiments to analyse protection in the temporal area, showing that, when a flat-surfaced striker struck the side of a cadaver head wearing a typical bicycle helmet, there was direct contact with the temporal area. Only one of the eight cadavers, of unknown age, suffered a skull fracture. They concluded that such contact was potentially harmful. Their article may suggest that typical bicycle helmets do not protect for impacts low at their sides.

Method - FEA

FEA simulated a moving head, wearing a quality bicycle helmet (Specialised S1) with a shell bonded to a polystyrene bead foam (EPS) liner, striking a fixed, flat, rigid surface. The initial yield stress of the 101 kg m⁻³ density EPS was 1.3 MPa. The impact site was 90° from the crown, at the side. The velocity components were varied (Table 1) to cover the cadaver tests1 and related conditions. The effective impact energy $E$ of the experiments1, defined as the energy input to the helmet up to the time when the moving striker of mass $m_s$ and initially stationary head plus helmet of mass $m_h$ have a common velocity, is given by

$$E = \frac{m_h}{m_h + m_s} E_s$$

where $E_s$ is the initial striker kinetic energy. Since $m_s = 36.5$ kg and a typical $m_h = 5$ kg, simulations with a fixed road surface should have a head/helmet velocity of 5.72 m s⁻¹ to achieve the experimental effective energy $E$. The head, taken as a rigid body with appropriate mass and moments of inertia³, had a compliant scalp.
Table 1 Right side of a Specialised S1 helmet obliquely impacting a fixed rigid flat surface

<table>
<thead>
<tr>
<th>Simulation</th>
<th>( V_N )</th>
<th>( V_T )</th>
<th>( F_N )</th>
<th>( V_N ) min</th>
<th>( a_{max} ) g</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>5.72</td>
<td>0</td>
<td>&gt;5.2</td>
<td>4.37</td>
<td>&gt;120</td>
</tr>
<tr>
<td>B</td>
<td>5.72</td>
<td>5.0</td>
<td>&gt;8.9</td>
<td>2.88</td>
<td>&gt;158</td>
</tr>
<tr>
<td>C</td>
<td>5.4</td>
<td>0</td>
<td>&gt;4.8</td>
<td>3.95</td>
<td>&gt;120</td>
</tr>
<tr>
<td>D</td>
<td>5.4</td>
<td>5.0</td>
<td>8.69</td>
<td>0</td>
<td>150</td>
</tr>
</tbody>
</table>

RESULTS

For an oblique impact with normal velocity component \( V_N = 5.4 \text{ m s}^{-1} \), and tangential velocity component \( V_T = 5.0 \text{ m s}^{-1} \), FEA predicted a peak head linear acceleration of 150 g (Table 1) after 6.0 ms. Figure 1a shows how the scalp in the headform ear region just touched the ‘road’ surface. Figure 1b shows the area of crushed EPS at the side of the helmet after 6 ms is roughly semi-circular, centred on the lower edge of the helmet. As the peak acceleration was less than the 275 g limit allowed by EN 1078, the helmet should protect the wearer’s head from injury. However, in a direct impact with \( V_N = 5.4 \text{ m s}^{-1} \) and \( V_T = 0 \text{ m s}^{-1} \), the simulation stopped after 5 ms, when the direct force on the head had reached 5 kN; the liner had bottomed out in the impact area, allowing the ear region of the headform almost to contact the road.

Oblique impacts cause a less severe peak head acceleration than direct impacts with the same \( V_N \) because sliding of the helmet on the head brings uncrushed EPS foam into the impact contact region, and hence improves the protection, compared with direct impacts. Head rotation is necessary before the ear region comes into contact with the road, and its direction differs between the oblique and direct impacts.

When the effective impact energy of the experiments was used (cases A and B in Table 1) the simulations ceased due to excessive foam deformation, just before the headform side contacted the ‘road’. Figure 2 shows that the force normal to the road and head surfaces varies similarly with time, with the slope being slightly higher when \( V_N \) is higher. The helmet was designed to pass EN 1078, with \( V_N = 5.4 \text{ m s}^{-1} \) and \( V_T = 0 \text{ m s}^{-1} \), for impact sites higher up at the side. At these sites a larger area of helmet contacts the road than in the Depreitere simulation (figure 1a), so the helmet is expected to perform better. Road contact with the temporal bone or zygomatic arch only leads to brain injury if the impact velocity is high. Simulation B (Table 1) predicted such contact when the velocity \( V_N \) had slowed to 2.9 m s\(^{-1}\). The helmet liner had therefore, by crushing, safely absorbed 75% of the impact kinetic energy associated with \( V_N \).

DISCUSSION

Current bicycle helmets cannot protect against injuries in all circumstances. Novel designs that provide very high levels of impact protection might be bulky and uncomfortable, and hence less likely to be worn. The experimental conditions represent a crash type that appears more severe than average, with a high direct velocity component, a zero tangential velocity component, and an impact site low on the helmet. As neither the peak impact forces were measured, nor high-speed video used to show when temple-to-striker contact took place in the impact sequence, the authors could not quantify the helmet protection performance. Because cheek tissue of the side

Fig. 1. FEA simulation of an impact at the side of a Specialized S1 helmet, after 6 ms, with velocities \( V_N = 5.4 \text{ m s}^{-1} \) and \( V_T = 5.0 \text{ m s}^{-1} \): a) frontal view with the scalp just touching the road surface, b) side view, showing contours of compressive stress \( \sigma_{22} \) (MPa); these are high where the foam is highly compressed.
of cadaver heads deforms in the experiments, observation of contact by paint transfer may not indicate more than a low-force impact. The FEA predictions suggest that, although a skull to flat-striker contact occurs, the risk of brain injury in typical oblique impacts at $90^\circ$ at the side of the head is probably insignificant.

Depreitere et al.\textsuperscript{1} described how a helmet with increased coverage of the temple region prevented skull to striker contact. For racing cyclists the extra impact protection will be negated by the increased thermal insulation of the head. The finding, that a larger distance from the bottom edge of the helmet to the Frankfort plane increases the risk of skull to road contact, is important for individuals with long heads. However, it is necessary to show that high energy impacts (leading to severe head injuries) occur frequently at the level of the ear, before a modification of EN 1078, to include impact tests at such sites, is likely.

**CONCLUSIONS**

FEA showed that, in the experiments carried out with helmeted cadavers\textsuperscript{1}, the helmet probably provided considerable head protection, and the protection would have been greater if the impact with the road surface had been oblique. Hence, the likelihood of brain injury to a live cyclist, in an impact with similar parameters, is low. Although the protection of the side of the head could be improved by helmet redesign, current helmets appear to provide adequate protection for typical lateral head impacts.

**REFERENCES**

5. EN1078:1997 Helmets for pedal cyclists and for users of skateboards and roller skates, BSI, London.