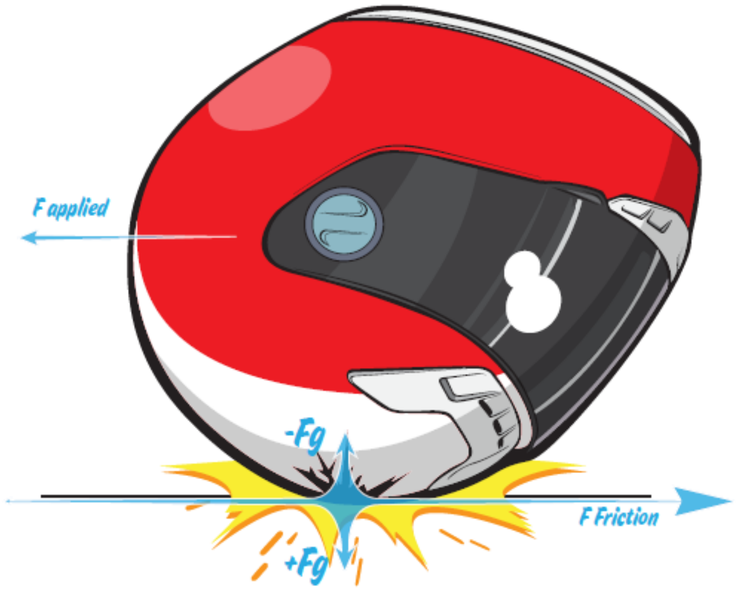
THE EFFECTS OF ROTATIONAL ACCELERATION ON A HELMETED HEAD

Figure 1



The majority of traumatic head injuries that motorcyclists and cyclists sustain are caused by rotational forces that are commonly generated as a result of the helmeted head of the rider having a glancing oblique impact with a hard bitumen surface or another unrelenting object.

There are two types of impacts involving either a translational (linear) force or a rotational force.

For impacts involving a pure translational force, the helmeted head of the rider undergoes rapid acceleration or deceleration movement in a straight line without rotating about the brain's centre of gravity which is located in the pineal region of the brain (Halliday, 1999).

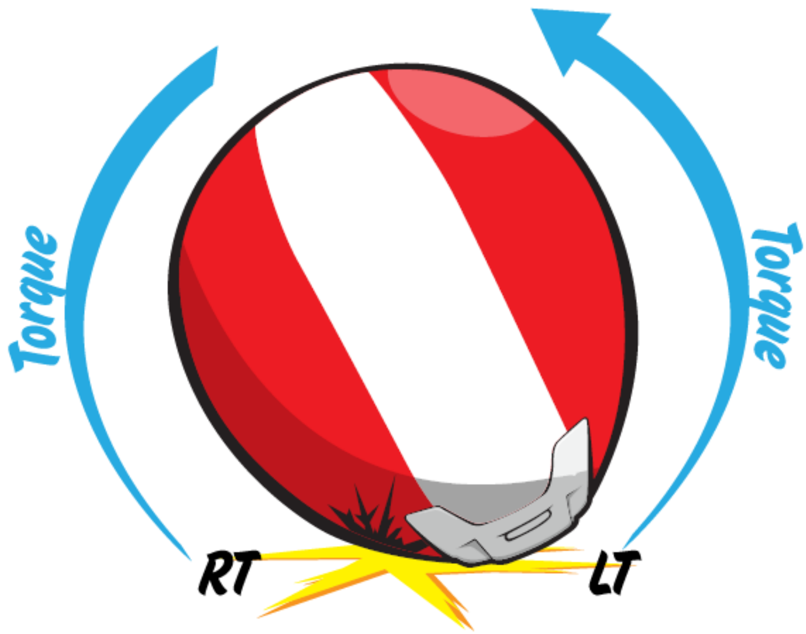
For impacts involving a pure rotational force, the helmeted head undergoes rapid rotational acceleration or deceleration about the brain's centre of gravity.

The majority of impacts involve a combination of translational and rotational forces and as a result the head will rotate around its point of articulation which is located in the neck as shown in figure 4.

The forces involved in an impact are shown in figure 1. These include: the downward force due to gravity which is the weight of the helmeted head (plus body); the upward force due to the impacting surface acting on the helmeted head which is the reaction force (This is Newton's 3rd Law of motion: for every action

there will be an equal and opposite reaction); the horizontal applied force which is the translational component of the combined force acting on the helmeted head of the rider and is always acting forward; and the horizontal frictional force due to the bitumen surface acting on the outer shell of the helmet which is always acting opposite to the applied horizontal force.

Figure 2

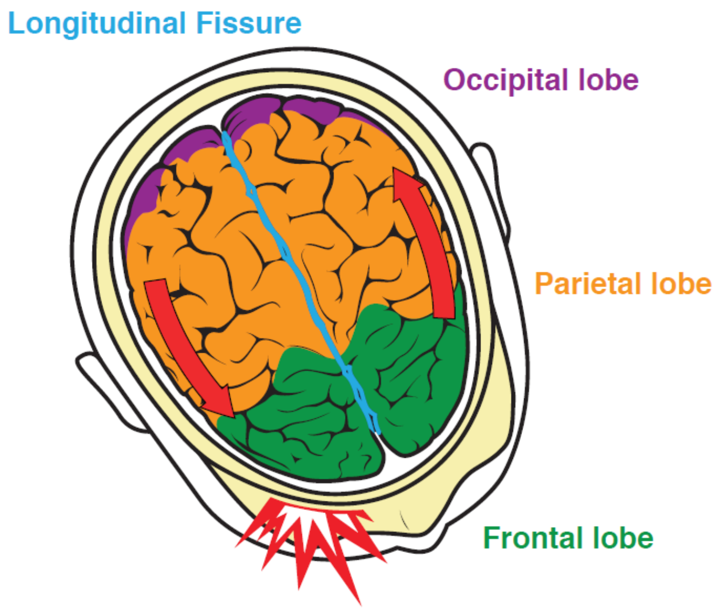


By referring to figure 2, the glancing oblique impact shown on the right side of the helmet, above the visor, results in the rider's head (and body) experiencing a severe twisting force which is the rotational component of the combined force. The twisting force is generally referred to as a torque.

The friction created between the outer shell of the helmet and the hard surface, such as, a bitumen surface, creates a momentarily gripping effect on the helmet resulting in the rider's helmeted head undergoing rotational forces involving deceleration or acceleration effects on the brain.

Finan et al (2008) found, in only one oblique impact scenario that by reducing the friction between the surfaces of the outer shell of the helmet and the impacting surface the rotational acceleration of the head would decrease.

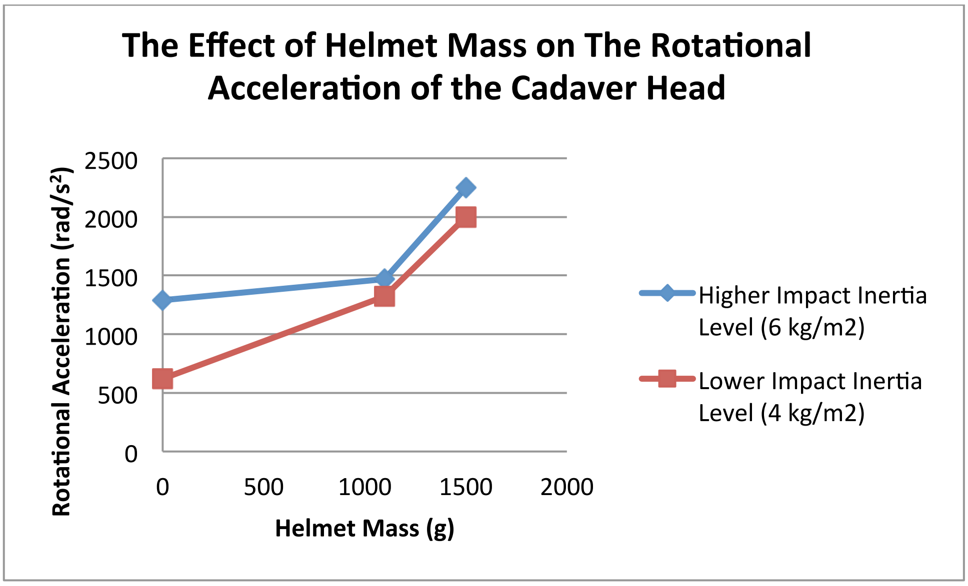
Figure 3



The brain is a jelly like soft tissue suspended within the enclosure of the hard skull in a bath of cerebral spinal fluid. The brain is covered by three membrane layers in which the outer-most layer, called the dura-mater, is connected to the inside of the skull at various suture points which serve to suspend the brain within the skull. The brain sits atop the brain stem and the spinal cord extends from there. The spinal cord passes out through a hole in the base of the skull called the foramen magnum. The mass of the human brain is roughly 1.5 kg.

When the rider's head and helmet (= helmeted head) is subjected to an oblique impact force (= a glancing twisting force), the helmeted head undergoes rapid rotational movement about its point of articulation. The rapid rotational acceleration or deceleration result in shearing forces affecting the different brain masses thereby causing stretching and tearing of nerve axon fibres and rupturing of bridging veins. The shearing forces occur markedly at junctions between brain tissues of different densities, that is, gray matter has a greater density than white matter resulting in the brain to move at different rates (Halliday, 1999). For example, the inner part of the brain will lag behind the outer part of the brain. Aldman (1984), reported the two tolerance limits for rotational acceleration are 1,800 rad/s^2 for concussion and 5,000 rad/s^2 for bridging vein rupture.

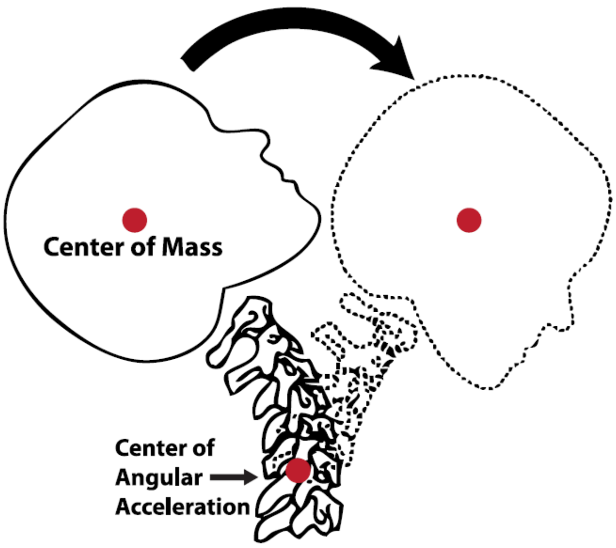
The greater the mass of the helmet on the rider's head the greater the rotational acceleration or deceleration effects will be on the brain. According to Corner et al (1987), "the effect of added mass to the head on rotational acceleration seems to increase slowly up to 1,000 gm then increase at a greater rate". See graph 1 below.



Graph 1

The above graph shows the effects of added mass to the cadaver head and the effects on the rotational acceleration of the cadaver for two levels of impact inertia. (Corner et al, 1987)

Figure 4



According to Halliday (1999), rotational acceleration of the brain does not occur alone in the majority of impacts but instead "the effects of rotational acceleration

are seen clinically only as a component of angular acceleration" and that "interactions between the head and neck favour the production of angular acceleration upon impact". Halliday also states, "combination of translational and rotational acceleration, angular acceleration is the most common form of inertial injury" of the head.

Figure 4 (Halliday, 1999) shows the centre of angular acceleration (and deceleration) located at about the sixth cervical vertebrae in the lower cervical spine.

For impacts involving angular acceleration the brain's centre of gravity will rapidly bend forward, backwards or sideways about the centre of angulation.

For impacts involving the centre of angular acceleration located higher in the cervical spine or at the base of the skull the head will exert greater rotational acceleration and deceleration effects on the brain.

The greater the degree of rotational acceleration experienced by the helmeted head will result in greater shearing injuries sustained by the brain.

The magnitude and duration time of the angular acceleration and deceleration will determine the seriousness of the brain injury sustained.

Figure 5

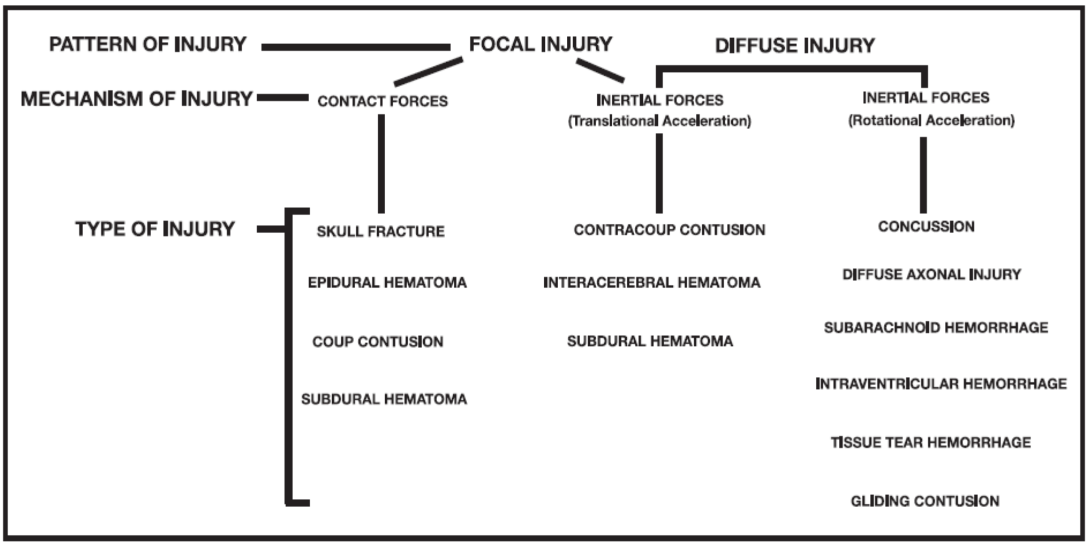


Figure 5 (Halliday, 1999) shows the mechanism of injury for different types of head injuries.

Rotational acceleration of the head is considered to produce diffuse brain injuries while translational (linear) acceleration produces either diffuse or focal brain injuries.

An example of an accident resulting in a diffuse brain injury would involve a glancing oblique impact to the head which generates shear forces within the brain causing tearing of nerve fibres (axons) and tiny veins, that is, a Diffuse Axonal Injury (DAI).

An example of an accident resulting in a focal brain injury would involve a direct impact to the head which causes the brain to strike the inside surface of the skull thereby resulting in bruising and/or bleeding (haematoma) to the brain at the site closest to the point of impact. This type of focal injury is a coup injury.

Another example is when a severe direct impact to the head causes the brain to bounce inside the skull thereby injuring the brain directly opposite the point of impact. The injury sustained is a contra coup injury.

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Figures 1, 2 and 3: provided by Strategic Sports Ltd (Hong Kong)

References

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