Newton’s Laws, G-forces and the Impact on the Brain

Zasady Newtona, siła grawitacyjna a ich wpływ na mózg

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Abstract

The thrill to go fast and push boundaries is something that many seek. From John Stapp’s rocket sled at Edwards Air Force Base in the late 1950’s to today’s Formula 1 drivers, the “need for speed” is broadcast across TV screens weekly. So too are the horror stories of crashes, many at over 300 km/hr. Yet “need for speed” continues. It appears that the higher and faster the rollercoaster, the better. This leads to several questions. How does the brain stand up to speed and G-forces? Do Newton’s Laws still have reference in today’s world?

There has been much attention in the general press on the possibility that high G-force roller-coasters are inducing brain injury in riders. However, research does not wholeheartedly support this notion, but rather the risk of brain injury from a rollercoaster is not in the rides, but in the rider — caused by previously undetected brain or neck conditions. That said there is some truth that high G-forces do affect the brain at a chemical and structural level. This paper will discuss the mechanism of head injury at speed and generally what Newton’s Law means in a neurological setting in today’s world. Formula 1 racing and rollercoaster rides will be evaluated within a neuroscience context. (JNNN 2019;8(3):133–137)

Key Words: concussion, head injury, Newton’s laws, Formula 1

Introduction

When thinking about head injury, one needs to first understand forces and the way they impact the body. Gravitational force, or G-force, is the force of gravity on a particular body — a measurement (in G’s) of acceleration that causes the perception of weight. It has significant applications in scientific & engineering fields especially regarding racing cars, fighter jets, large engines and rollercoasters.
This paper will discuss the mechanism of head injury at speed and generally what Newton's Law means in a neurological setting in today's world. Formula 1 racing and rollercoaster rides will be evaluated within a neuroscience context.

**Literature review**

It is interesting to note (see Table 1) that the force of gravity whilst just standing on the earth, increases markedly with a slap on the back. Then further when in a car or a rollercoaster and even more if having sustained a concussion.

Table 1. How many G's?

<table>
<thead>
<tr>
<th>Activity</th>
<th>How many G's</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standing on the Earth</td>
<td>1 G</td>
</tr>
<tr>
<td>Rollercoasters</td>
<td>3.5–6.3 G</td>
</tr>
<tr>
<td>A slap on the back</td>
<td>4.1 G</td>
</tr>
<tr>
<td>Formula 1 Racing car</td>
<td>5 G</td>
</tr>
<tr>
<td>The luge at Whistler</td>
<td>5.2 G</td>
</tr>
<tr>
<td>'Plopping' into a chair</td>
<td>10.1 G</td>
</tr>
<tr>
<td>Sneezing (open mouth)</td>
<td>2.9 G</td>
</tr>
<tr>
<td>Concussion</td>
<td>80–100 G</td>
</tr>
</tbody>
</table>


In today's modern age, Sir Isaac Newton's theories and laws are still included in the curriculum taught to students at school. From his theories of optics and calculus, to his groundbreaking work on the laws of motion and gravity, which formed the basis for modern physics, he dominates the fields of science, astronomy, physics and the natural world, proving invaluable to centuries of mathematicians, engineers and scientists.

In health, the Valsalva maneuver is a technique of force used to equalise pressure [2]. People perform the Valsalva maneuver regularly without knowing it. For example, it is used to increase colonic pressure to induce a bowel movement and it may also be beneficial when used intentionally to try to regulate heart rhythms. It is also used when experiencing a change in altitude to help equalise the ears by forcing them to 'pop', such as when scuba diving or in aeroplanes. The main side effect of using the Valsalva maneuver is hypotension and resultant forces impacting intra-ocular, intra-abdominal and intra-cerebral pressure.

These forces are also produced in the acts of vomiting, coughing and sneezing. As neuroscience nurses, the knowledge regarding the impact of these forces is known to be troublesome in relation to the consequences of these forces on intra-cerebral pressure and the homeostasis of the brain. It should be kept in mind that the involuntary act of sneezing has ramifications from a G-force perspective. The act of sneezing with an open mouth has a force of 2.9 G's. Yet holding in a sneeze internally redirects the force and this can result in eye injury, ruptured ear drum, herniated nucleus pulposis (herniated disc) and throat injury [3].

**Newton's First Law: (Inertia).** An object will remain at rest, and an object will remain in motion, unless acted upon by an unbalanced force. For example, a fast car hits a brick wall. The car stops… but the person does not. Since an object at rest stays at rest, rollercoasters have to be pushed or pulled along the track. In this way, potential energy is stored for the entire ride. At the top, the rollercoaster is put into motion and will not stop until the brakes are applied at the end of the ride.

The world's fastest rollercoaster is the *Formula Rossa* rollercoaster in Ferrari World, Abu Dhabi, United Arab Emirates. It is 53 m high and has a maximum speed of 240 km/h via a hydraulic slingshot launch. In this way, acceleration is 0 to 240 km/h in 4 seconds. The G-force is 4.8 G, requiring the rider to wear goggles for eye protection [4].

**Newton's Second Law: (Force = mass x acceleration).** This law explains how the velocity of an object changes when it is subjected to an external force. This is felt when going down hills. The coaster cars and your body have mass. The gravity provides acceleration, which causes force. The rider feels the force as it moves the cars along the track. The track directs the force and the cars.

In positive G’s, the body feels heavier — at the bottom of the hills, turns and loops. For example, a 70 kg person at 2 G’s would have the perception of 140 kg and at 3 G’s it would feel like 280 kg. Whereas with negative G’s, the body feels weightless — at the top of the hills.

**Newton's Third Law: (Action/reaction).** For every action (force), there is an equal and opposite reaction. For example, as your body is pushed down into the seat of the rollercoaster, the seat pushes back.

Newton's Laws permeate throughout engineering and science fields and are still current in today's practice. It was Dr John Stapp, a United States Air Force Colonel, flight surgeon, physician, biophysicist, and pioneer in studying the effects of acceleration and deceleration forces on humans, who put Newton's Laws to the test on the human body.

At New Mexico's Air Force Base, December 10, 1954, John Stapp was strapped into the *Sonic Wind* rocket sled. His arms and legs were secured. There was no windscreen, so he wore goggles, a mouthguard and a helmet. The sled was powered by nine solid fuel rockets and it fired and propelled him more than 3,000 feet in a few seconds. He came to an abrupt stop and experienced a force equivalent to 46.2 G. Not without injury, he walked away with the world land speed record, 632...
miles/hour, which he still holds today, giving him the title of "the Fastest Man on Earth" [5]. However, the blood vessels in his eyes had burst, rendering him temporarily blind. He also sustained bilateral wrist and rib fractures.

The outcome of these experiments allowed for the development of improved pilot harnesses and aircraft seats, modern crash-test dummies, the ejection seat and high-altitude pilot suits. Stapp’s research improved aircraft safety and also led to the development of the shoulder seat belt. In September 1966, President Johnson, with John Stapp present, signed the Highway Safety Act, in which it was required that all new cars, as of 1968, sold in the USA, be fitted with seat belts [6].

When thinking of acceleration, the picture that formulates is usually of a sports car doing 0 to 60 in six seconds. However, acceleration is any change in the velocity of an object — going faster, slowing down or changing direction. Therefore, on a rollercoaster, the G-forces are felt when rounding tight bends and thrown against the side of the seat (a change in direction) just as much as when falling from height (accelerate) or screeching to a stop (decelerate). The thrill is felt, but there is no fainting, because the rollercoaster was designed to be within the G-force tolerance of the average person. However, the amount of tolerable G-forces differs by individual and it also depends on several factors: the direction in which the G-forces are felt, the amount of G’s involved, and how long those G’s last [7].

At sea level, or 1 G, humans require 22 millimeters of mercury blood pressure to pump sufficient blood from the heart to the brain. In 2 G’s, twice that pressure is needed, in 3 G’s, three times, and so on. Even with a G-force of 4 or 5, the heart struggles to summon the necessary pressure. Blood pools in the lower extremities and the brain fails to be adequately oxygenated. Most people then faint.

Fighter pilots can handle greater head-to-toe G forces — up to 8 or 9 G’s — and for longer periods by wearing anti-G suits. These specialised suits use air bladders to constrict the legs and abdomen during high G’s to keep blood in the upper body. Fighter pilots can further increase their G-tolerance by training in centrifuges, which create artificial G’s, and by learning specialised breathing and muscle-tensing techniques. Magnitude and duration of the forces are as critical as direction. Whilst John Stapp showed that people can withstand much higher G-forces than had long been thought, there is a limit to what most people can tolerate.

Princess Diana was a catastrophic example of how G-forces affect the human body. It was estimated that the G-forces on her chest were around 70 G’s and 100 G’s on her head. The acceleration caused a fatal tear in her pulmonary artery. If Princess Diana had been wearing a seatbelt, the G-forces would have been less and she may have lived [8].

While Formula 1 (F1) racing drivers may feel around 5-G’s, under heavy braking, they can experience over 100-G’s if a crash causes them to decelerate quickly over a short distance.

The weekend of May 1st 1994, during the San Marino Grand Prix, was Formula 1’s worst race weekend in history. That weekend of racing in Imola, Italy, saw the death of Austrian, Roland Ratzenberger in practice and that of Brazilian, Ayrton Senna the following race day.

For some, the eyes are especially susceptible to G-forces and some of the first signs of problems in the cockpit arise from partial loss of vision. Pilots know it as ‘greyout’ — greying of vision due to reduced blood flow to the eyes. This can serve as a warning of the decreased blood flow to the head. Consciousness is maintained but blood flow to the eyes is compromised. However in some
In 2002 Smith & Meaney [12] suggested that the human body can withstand very large G-forces when they occur over very short periods of time, which is the current thought today. They suggested that the loss of consciousness is from restriction of blood flow rather than mechanical injury to the brain. Their studies illustrated that to injure the brain, there needs to be greater linear force (G's) as well as rotational force. They went on to say that neck or back injuries would be far more likely than brain injuries from rollercoasters.

Again, the thought in 2003 was that the risk of brain injury from a rollercoaster is not in the rides, but in the rider — caused by previously undetected brain conditions or spine injuries from the force in the turns [13].

Yamakami et al. [14] and Roldan-Valadez et al. [15] described anecdotal case reports of potential causal relationships of patients suffering brain bleeding around the time of riding a rollercoaster. This is now not supported by epidemiological or scientific data.

Although Roldan-Valadez et al. [15] presented a paediatric patient with a subdural haematoma, fourteen days after having ridden a rollercoaster, the causative element cannot be correlated entirely to the rollercoaster. The results are also limited as there was only one individual in this study.

Pfister, et al. [16] also agreed that it’s not the ride, but the rider and said that there was an extremely low risk of TBI due to head motions induced by rollercoaster rides. Similarly, Kuo et al. [17] suggested that rollercoaster rides do not present an immediate risk of acute brain injury. However, head motion and brain deformation during rollercoaster rides are highly sensitive to individual subjects — who already are predisposed to brain injury.

However, in 2018 there was a growing concern about the G-force that is exerted on people as they ride these faster rollercoasters, as the desire to go faster is ever-present. In October 2018, New Jersey, USA became the first state to limit G-forces on theme park rides.

The American Association of Neurological Surgeons has assembled a national committee of neurosurgeons, NASA scientists and engineers that are now looking at how the stress of G-forces from rollercoasters might affect the brain, specifically how the brain is bounced around inside the skull on these rides. The committee has not yet reached any conclusions [18].

Zhu et al. [19] describes the studying animals such as the barbary sheep and woodpeckers have given insight into how these animals cope with extreme force impacts. Inspired by the woodpecker’s head, researchers have developed a casing for aircraft flight recorders that can withstand a G-force of up to 60,000-G’s (previously 3.400 G’s).

**Conclusions**

Being wrapped in cottonwool is not an option. Sport and fun are synonymous. The desire to go fast is thrilling and it seems that the faster the rollercoaster, the better! Keeping a child safe is a parent’s obligation and companies have that same obligation of safety. As demonstrated by Stapp in the 1950’s, humans can be subjected to high G-forces and survive, as long as it is for a short duration. Magnitude and duration are as critical as direction, when it comes to forces. Safety is paramount in industries where G-forces are found — engineering, space travel,
F1 racing and theme parks. With this in mind and knowing the mechanism of injury, F1 responded with changes to car design and changes to rules and procedures following driver injury.

Rollercoasters that generate G-forces for the pursuit of fun-filled terror must be conscious of the pressure that is placed on the human body during these rides. Safety mechanisms and short duration of twists, turns and speed, must be taken into account and adapted for the safety of all.

With this knowledge of G-forces, people are better placed to judge whether or not to put their bodies through these forces. It must also be clear that if a person knows or suspects they might have a brain or neck injury, then obviously it is unwise to participate in an activity that could compromise their health. Warnings at each ride are placed for a reason, informed knowledge and decision-making as well as coverage for litigation purposes. These must be taken seriously, as it is a fine line between being well and unwell.

**Implications for Nursing Practice**

Neuroscience nurses play a role in teaching the public — through seminars, school educational sessions and governments and companies have an obligation for public safety. Although life is becoming a minefield of “Safe Operating Practices” and every product has a warning attached, fun activities are encouraged, just within reason. The brain, within its' hardened case, is protected but also vulnerable to changes in pressure and force. Pre-existing conditions of the brain or neck, whether known or not, plays a role in injury from rollercoasters and theme park rides. Some obligation must rest with the individual. That is, the issue remains with the rider — their health and informed decision on whether or not to ride.

**References**


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