

Negative *g*-Force Ocular Trauma Caused by a Rapidly Spinning Carousel

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Key Words

g Force · Acceleration · Subconjunctival hemorrhage · Ocular trauma

Abstract

We present a case of a 10-year-old boy who presented with bilateral diffuse subconjunctival hemorrhages after spinning rapidly on a carousel attached to an electrical scooter. We present his clinical course and discuss the physics and pathophysiology of this unique mechanism of ocular trauma.

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Introduction

Ocular trauma is usually categorized into direct mechanical and indirect trauma. However, acceleration forces also constitute a possible mechanism of ocular injury, which may cause significant damage without any direct contact with the eye. The most demonstrative example for severe ocular trauma by this mechanism is the 'Shaken Baby syndrome'. Typical ocular findings in this entity include retinal hemorrhages and retinoschisis, the pathogenesis of which is attributed to acceleration-deceleration forces and increased intracranial intravascular pressure [1]. Acceleration forces causing ocular trauma have also been described in bungee jumps [2] and rollercoaster rides [3].

We report a patient who suffered ocular injury caused by radial acceleration on a carousel. The physics and pathophysiology of this unusual pathogenic mechanism are reviewed.

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Case Report

A healthy, 10-year-old boy was examined in our institution due to bilateral diffuse subconjunctival hemorrhage. He had mounted a carousel that was attached to an electrical scooter, and had spun round on it very rapidly. The boy had no control of the carousel, but fortunately an adult managed to disconnect the scooter. The rapid spinning lasted for about 1 min, during which the boy suffered an intense headache, but did not lose consciousness. After dismounting the carousel, the boy complained of a headache, his face was swollen, both eyes were red and he was brought to the emergency room in our institution.

On examination, visual acuity was 20/20 OU. Bilateral subconjunctival hemorrhages were noted in both eyes (fig. 1). The remainder of the examination was normal, with clear corneas and lenses, no intraocular hemorrhage of any kind and normal dilated fundus examination. Intraocular pressure was 12 mm Hg in both eyes, and pupillary responses were normal. There was no limitation in ocular motility. Additional findings of the physical examination included a mild swelling and periocular petechiae (fig. 1a) as well as petechiae in both ear canals and on the soft palate.

Head CT was normal, with no evidence for intracranial or orbital hemorrhage. Optical coherence tomography showed a normal retinal structure (fig. 1d). The subconjunctival hemorrhages enlarged initially, but were then gradually resorbed and had disappeared completely within 1 month (fig. 2). Visual acuity remained 20/20 throughout the follow-up.

Discussion

An object travelling linearly at a constant speed has no linear acceleration. However, an object travelling in a circular route at a constant speed also has a constant radial acceleration, because its direction of movement is constantly changing. For example, a passenger in a car travelling forward feels no acceleration, but when the car makes a turn without changing its speed the passenger will feel the 'pull' of the radial acceleration.

The boy we describe was 1.40 m tall, the carousel was 1.20 m in diameter, and the electrical scooter attached to it is capable of reaching a maximum speed of 40 km/h. While spinning, the boy's body was reported to be tilted back. Assuming that the distance between the center of the carousel and the boy's head was 1.20 m and that the scooter was spinning the carousel at half of its maximal potential speed (20 km/h), the acceleration force affecting the boy can be calculated according to the formula:

$$a_r = \frac{v^2}{R}$$

where a_r = radial acceleration, v = velocity and R = radius (distance from center to head). Therefore:

$$a_r = \frac{\left(20 \frac{\text{km}}{\text{h}}\right)^2}{1.2 \text{ m}} = \frac{\left(5.55 \frac{\text{m}}{\text{s}}\right)^2}{1.2 \text{ m}} = 25.67 \text{ m/s}^2.$$

Acceleration forces may be expressed as '*g*' forces, which are multiples of the constant acceleration exerted by the earth's gravity. Since 1 *g* equals 9.81 m/s², the radial acceleration force to which our patient was subjected was 2.61 *g*.

Along the vertical axis, positive *g* force drives blood from the head to the feet, and negative *g* force drives blood from the feet to the head. The human body is much more tolerant to positive *g* forces, as a typical person can withstand 4–5 *g*, and pilots who undergo high-*g*

training can withstand even 9 *g* [4, 5]. Conversely, the body cannot be trained to tolerate negative *g* forces. Ocular discomfort occurs almost immediately, and subconjunctival hemorrhages occur at 2–3 *g*. Confusion and loss of consciousness occur at 4–5 *g* [4].

Previous reports of pilots subjected to 3–4 *g* negative *g* force include complaints of severe headache, a sensation that ‘the eyes are popping out of the head’, red vision, facial swelling, petechiae and diffuse, subconjunctival hemorrhages. These symptoms and signs are caused by the acceleration forces leading to congestion and elevated intravascular pressure [4, 6]. Ocular hemorrhages were also demonstrated in a porcine model in which animals were subjected to nonimpact high-speed rotation [7].

Our patient was exposed to similar physical conditions which resulted in a similar clinical presentation, and the radial acceleration created by the rapidly spinning carousel was close to that of a plummeting jet. He was supposedly subjected to 2.61 *g* of radial acceleration pushing blood from his feet towards his head, which is just under the human body’s limit of tolerability. This force precluded venous return and caused marked congestion and elevated intravascular pressure in his head, resulting in headache, facial swelling, diffuse bilateral subconjunctival hemorrhages and petechiae in the ear canals and on the soft palate. Fortunately, there were no retinal hemorrhages. It is possible that a longer duration or higher magnitude of exposure to this radial acceleration would have caused retinal hemorrhages as well, as seen in the ‘Shaken Baby syndrome’. These babies are more physically fragile, and are often subject to repeated and prolonged abuse that results in more severe ocular and systemic damage at presentation.

In conclusion, this case illustrates the low tolerability of the human body, and the eyes in particular, to negative *g* forces. This mechanism of injury is usually dealt with in aviation medicine, and is not encountered frequently by general physicians and ophthalmologists. Awareness of this unique mechanism of ocular trauma is nevertheless important, as it can occur even in the most unexpected circumstances such as playing in the playground.

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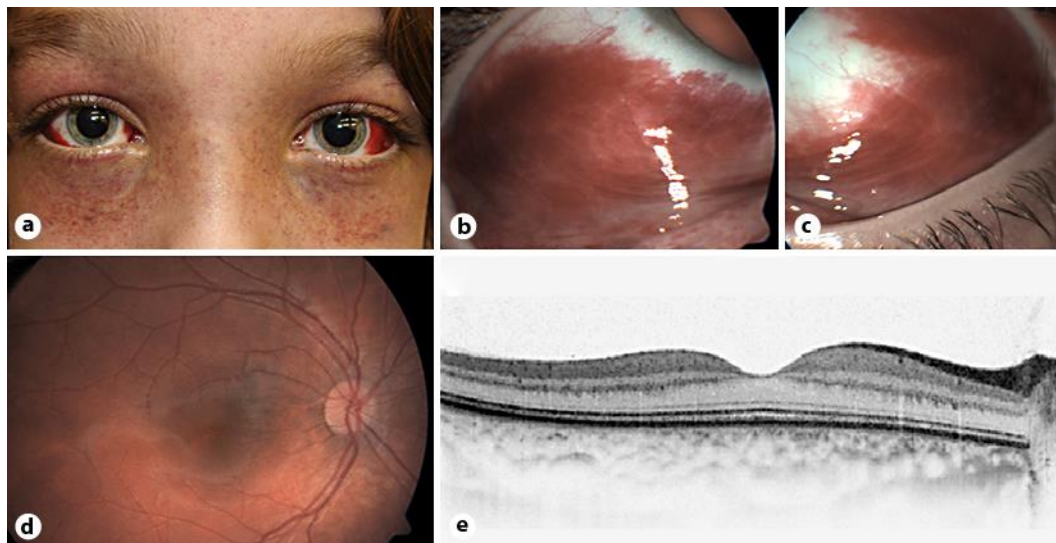


Fig. 1. Findings at presentation: mild facial swelling and periocular petechiae (a), bilateral subconjunctival hemorrhages in the right (b) and left eye (c), normal fundus (right eye shown) (d) and OCT demonstrating normal macular structure (right eye shown) (e).



Fig. 2. The subconjunctival hemorrhages at presentation (a), after 5 days (b) and complete resolution after 1 month (c).