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Performance of children and adult alpine helmets under characteristic falling conditions

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Abstract

Helmeted and unhelmeted impacts of Hybrid III 6-year-old and 50th percentile adult head forms were conducted to assess performance of helmets at characteristic falling conditions at three impact sites. The child head form was impacted at 3.3 m/s, and the adult at 5.5 m/s. The child helmet reduced linear and rotational acceleration by 64% and 62%, compared to the adult helmet which reduced levels by 48% and 50% respectively. The child helmet performed well under lower impact velocity conditions than those tested by helmet certification standards, it is hypothesized the soft comfort foam is responsible for this performance.

Keywords: Concussion; impact biomechanics; alpine helmets; head injury

1. Introduction

Alpine skiing and snowboarding are common activities for all ages, though participation exposes people to the inherent risks of the sport such as head injuries. In order to mitigate the risk of head injuries, helmets are commonly used. Helmets have been shown to reduce the risk of sustaining head injuries [1-4] as well as their severity [1,3]. While certified helmets are designed to reduce the risk of head injuries, they are not expected to prevent all injuries in all circumstances [5]. Alpine helmet certification is based on the ability to manage the peak linear acceleration of impacts, which is predominantly responsible for causing catastrophic injuries such as skull fracture [6,7]. Helmets pass standards if they limit linear acceleration to below a threshold of 300 g [8], or 250 g [9,10] for a prescribed impact velocity (5.42 - 6.8 m/s), head form, and impact anvil (usually a flat steel anvil). Helmets are effective at reducing the risk of head injuries associated with linear motion such as skull fractures; however their effectiveness at protecting against other injuries such as concussion is not assessed by standards. Concussions are more associated with rotational motion ([7,11-14]). In all impacts, both linear and rotational motions are present but both need to be managed by a helmet to reduce the risk of all types of injuries.

Falls are a common cause of head and brain injury in alpine skiing [15,16]. Because young children are smaller, they tend to fall closer to the ground resulting in lower impact velocity compared to adults. Additionally, young children have smaller heads that will respond with higher magnitude accelerations to similar impacts when compared to adults [17]. These factors create unique impact characteristics between age groups, something that is not accounted for in helmet standards testing. Recently, a new standard testing method has been proposed for the CEN [18]. Instead of a flat steel anvil, the proposed standard impacts a 45 degree steel anvil covered in sandpaper at 6.5 m/s to elicit rotation [18]. Thresholds have not yet been set, but this test reflects a more representative condition of hitting a ski slope, emphasizing protection against both linear and rotational motion from impacts.

Low velocity motion (skiing slowly) has been identified as a risk factor for head injuries in alpine skiing [19]. At low velocity, rotational motion of the body from actions such as “catching an edge” will be minimized as the participant will have time to recover at least partially or alter their fall motion. As a result, head impact velocity could be similar to a free drop, with some

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influence from limbs bracing the fall. Low velocity head impacts can still cause an injury, though the injury is likely not a skull fracture and more likely to be concussion. The impact characteristics are different at low velocity, and helmets do not have to pass any standards at these velocities. Many alpine helmets use an expanded polystyrene (EPS) liner which is effective at managing high energy impacts [20] though at low velocity it could be too stiff to manage lower impact energies.

Standards test the ability of a helmet to withstand high energy impacts however children don't fall from the same height as adults, reducing the impact velocity to lower than certification level. Since both adult and child helmets alike are tested to the same standard, it is unknown how well the helmet will perform for lower velocity falls. This study is aimed to assess the protective capacity of alpine helmets for characteristic fall events, with impact velocities typical for adults and young children. It is hypothesized that the child helmet will be too stiff for the lower impact velocity, showing lower reduction in impact response compared to the adult helmet.

2. Body

2.1. Methods

Helmeted and unhelmeted impacts of the Hybrid III 6-year-old and 50th percentile adult head forms were conducted to determine helmet performance based on three metrics, linear acceleration, rotational acceleration, and rotational velocity using a certified alpine helmet as representative for alpine helmets. The impacts were conducted using a monorail drop system, hitting a 45 degree angled steel anvil covered with sandpaper. A single impact velocity was used for both children and adults, each representing a typical fall velocity for the age groups (6-years-old vs. adult), capable of causing concussion. Three impacts were conducted for each condition and location, with locations being the front, side, and rear. Figure 1 shows a helmeted side impact. No neck form was used. Helmet EPS liner thicknesses of the adult and child helmets were both 20 mm, with 9 mm and 15 mm of comfort foam respectively.

2.1.1. Monorail

To conduct the tests, a monorail drop rig system was used. A halo support drop carriage was used for the impacts, with the Hybrid III head forms sitting on the halo. The halo allowed for a free drop condition, permitting movement of the head in 6 degrees of freedom without interaction with the head form upon contact with the anvil. The drop carriage was attached to the monorail by ball bushings, allowing for low friction movement when released. The release mechanism was a pneumatic piston. The anvil used was a 45 degree steel anvil covered with sandpaper, following a presentation regarding the new proposed CEN standard [18]. Impact velocity was determined by a photoelectric time gate that was positioned within 0.02 m of the impact. The side impact condition is shown in Figure 1.

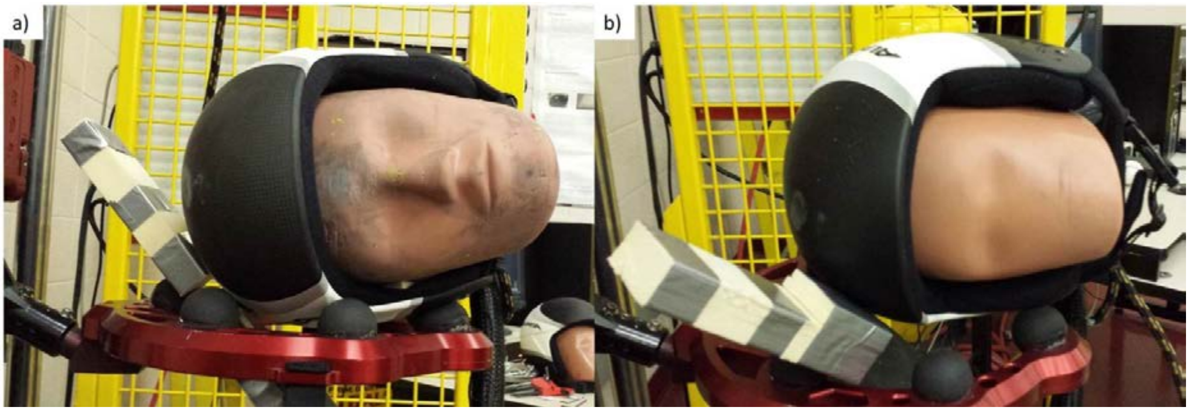

Figure 1. Side impact for the helmeted a) adult head form and b) 6-year-old head form

2.1.2. Impact Velocity

The goal was to impact at a velocity, typical of falls capable of causing concussion in each age group. To determine a velocity typical of concussive fall events, a database of falls resulting in concussion was examined. These cases were taken from patients aged 0-18 years old presenting to a major Canadian hospital. Each patient filled out a Neurotrauma Injury Report Form describing the event, including impact location, height of fall, impacting surface, as well as the age and height of the patients. Impact details were required to be confirmed by an eyewitness account to be included. The cases included all types of recreational activities, not limited to sports or alpine skiing, and represent examples of falls causing concussion. The 6-year-old group consisted of 7 patients