Foldable Bicycle Helmet

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Abstract
People ride bicycles for leisure, sport, and commuting purposes; therefore it is important to ensure cyclist safety in all areas. Bicycle helmets are important for rider protection, though they do have some inherent drawbacks. Storage of the helmet, when it is not in use, is one of the reasons why some riders choose not to wear head protection. A lightweight, collapsible helmet would assist in eliminating this market gap, allowing the user to store it in a bag, briefcase, or satchel. Background knowledge of bicycle helmet history, purpose, and design was established and included research on bicycle accident statistics, brain trauma and other injuries resulting from head collisions, current rigid helmet designs, current folding designs already on the market, and relevant patents. This information was analyzed to assist in the development and implementation of a folding helmet solution that would meet safety standards and user needs. The design was conceptualized, modeled, and prototyped to demonstrate folding functionality while finite element analysis and physical testing was performed to demonstrate the feasibility of helmet safety standards compliance. While further development and testing is necessary before bringing the design to market, the prototype provides a solution for creating a safer cycling community.

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The Need for Project

There is a need to increase the frequency of bicycle helmet use. Some cyclists do not wear helmets because they are bulky to store; a foldable helmet would alleviate this concern and increase helmet use. Studies have shown that wearing a bicycle helmet can reduce the risk of head and brain injury by approximately 85% (Refs 2,3). With an increasing population of cyclists in motor vehicle trafficked areas it is becoming more important to protect riders from possible injury or death. In addition to complying with legislation that requires the use of helmets, it is also important for a helmet to appeal to the user’s wants. Helmets can be bulky and as a result can discourage use because they cannot be easily stored in a backpack or desk drawer. A foldable solution could expand the market for helmets to users who are looking for a low profile storage option, and would improve the percentage of helmet-wearing cyclists on the road (Rep 3.2).

The Design Project Objectives and Requirements

The project goals are to design and prototype a foldable helmet that will pass the Consumer Product Safety Commission standards. The design will be evaluated using computer-aided finite element analysis along with physical testing of the prototype. Design Objectives

The goal of this project is to design a helmet that provides protection against head injury and is easier to store than current rigid helmets. Such a design would fill the market gap for some cyclists who are reluctant to wear helmets due to storage constraints.

Design Requirements (Rep 3.4)

The prototype helmet must be capable of folding to a size that would comfortably fit in a backpack or briefcase. It must also implement a simple and innovative folding method that does not require more than two or three steps to transform between the wearable and folded forms. Furthermore, it must be able to limit the acceleration of the head (a standard headform is used in testing) to less than 300 g during a 2 meter fall, as required by the Consumer Product Safety Commission Standards (CPSC, Ref 11).
Design Concepts Considered

Five design concepts were selected from 12 initial brainstormed solutions. The concepts were evaluated using a decision matrix and the highest scoring concept was chosen for further development.

**Honeycomb (Rep 5.2.1)**

A helmet consisting of four collapsible honeycomb structures was conceptualized due to honeycomb’s ability to absorb significant amounts of energy perpendicular to the hexagonal plane and its ability to collapse or be folded along the hexagonal plane. Each of the four sections would be individually collapsible to minimize helmet volume. This design would require hinges between the four honeycomb sections and possibly a rigid outer shell to prevent objects from penetrating through the helmet.

**Operating Stud (Rep 5.2.2)**

The operating stud concept incorporated pin hinges on opposite sides of the helmet to allow the helmet sections to be rotated into a flat position. Ribs of foam would run between the two hinges, which would be curved to have the shape of a helmet when fanned out. This success of this design would depend on the pin hinges withstanding high impact testing, a fail-safe hinge locking mechanism, and the ability to design nesting foam sections to allow for efficient folding.

**Fabric Casing #1 (Rep 5.2.3)**

The Fabric Casing #1 design implemented strips of flexible foam held together with a canvas-like exterior to form a helmet that would lie flat when unfolded. A cinch strap running around the lower perimeter of the helmet would pull the foam sections together to form the wearable helmet. The foam is cut such that when the cinch strap is tightened, the foam strips bind against each another so that objects cannot penetrate the exterior. This concept did not incorporate a rigid outer shell.

**Fabric Casing #2 (Rep 5.2.3)**

The Fabric Casing #2 concept consisted of a fabric liner against the scalp (or on the inside of the helmet), with small blocks of foam, or “islands” sewn to the outer surface of the canvas. This concept implemented a construction opposite from the Fabric Casing #1 concept; however it uses smaller “islands” of foam as opposed to longer strips. Each foam “island” was to have its own thin rigid shell on the helmet exterior.
Fluid Lined Fabric (Rep 5.2.4)

The Fluid Lined Fabric concept operated on the dispersion of impact energy through the movement of fluid between full and evacuated bladders. Small orifices between bladders would act as fluid dampers to assist in energy absorption during an impact, and would allow fluid pressure relief that would allow the helmet to be folded flat like a ski-hat.

Decision Matrix (Rep 5.3)

A decision matrix was generated to assist in the selection of the final design to be prototyped. The criteria used for design selection were: safety, manufacturability/cost, flatness, ease of folding, weight, and innovation. The importance of each design criterion was weighted to ensure that the final decision scoring reflected the most important criteria. The Fabric Casing #1 concept scored the highest in the matrix, and several components of the Fabric Casing #2 were incorporated with the design.

Recommended Design Concept

The helmet will consist of EPS foam cut into triangular pieces in a radial pattern attached to a canvas material that will be held together in the functional form with a cinch strap. When the strap is loosened, the helmet can be turned inside out.

Design Description (Rep 5.4.3)

The fundamental design entailed cutting a solid foam helmet into discrete pieces and joining each piece with a flexible shell on the outer helmet surface. Running along the lower perimeter of the helmet is a cinch cord, that when tightened, pulls the helmet into the wearable form. When the cinch cord is loosened, the helmet can be turned inside out and folded in half, resulting in a flat helmet with overall dimensions of 16” x 7.5” x 3”. Two winch mechanisms were incorporated above the user’s ears as a means to tighten the cinch cord.

Analytical Investigations (Rep 5.6, 7.4)

Finite element analysis serves as the primary metric of passing test standards. FEA includes the use of a scaled model of a head modeled as a completely rigid shell, with a mass of 5 kg. The goal of the analysis is to limit the peak allowable acceleration in the head to the CPSC standard of 300 g when subjected to a 2 m drop onto an anvil.

Experimental Investigations (Rep 7.5)

Physical testing of a prototype was conducted in an attempt to recreate CPSC standards. The testing serves as an additional learning tool to see how well the prototype performs outside of finite element
analyses. An accelerometer capable of gathering data to the necessary accelerations was used in the test set-up. A 3D printed model of a head was used to hold the accelerometer and weights to bring the final weight to the standard specified 5 kg. Helmets currently on the market that are known to have passed the tests were also tested to provide a baseline for comparison.

**Key Advantages of Recommended Concept**
This design allows for the helmet to become the flattest expanded polystyrene model currently being sold. This helmet fits inside of a backpack, thus accomplishes the main project goal.

**Financial Issues**

The current prototype design consists of 76 foam parts made of expanded polystyrene, which would be injection molded in full production. It is possible to machine the parts, but this would only be feasible in the prototype stage of development. The material cost is very low, but mold costs would be large depending on manufacturing methods, such as the use of over-molding for adhering the outer fabric layer, and mold size. Actual production costs are predicted to be manageable; however, the start-up cost will relatively high. The cost analysis for production costs and helmet pricing are still being conducted. Because this helmet provides more user features than a rigid helmet, and will also have higher than average production cost, it will command a higher price-per-helmet in the market.

**Recommended Improvements**

Part reduction and simplification is paramount to keeping the cost of this helmet low and allowing the product to enter the market at a competitive price. Manufacturing and assembly would require a large-scale operation to produce any amount of volume due to the complexity and number of parts in the current prototype. More materials could be tested for the outer shell as well, to reduce potential friction with the road during impact.

Most helmets on the market contain ventilation channels in order to keep the rider cool during use. These could be added in a future revision.