SAFER cycling: from crash avoidance to injury reduction - increased visibility and reduction of injuries by smart clothes and materials

Title: SAFER cycling: from crash avoidance to injury reduction - increased visibility and reduction of injuries by smart clothes and materials

Research area: Human Body Protection

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Summery

The pre-study focused on two key factors a) avoiding a crash involving bicyclists and b) reduce shoulder injuries in the event when a crash cannot be avoided. Our hypothesis is that many crashes involving cyclist could be avoided by increasing the visibility of the cyclist. Previous research has identified a need for improved protection for bicyclists. There is a lack of actions for protection of shoulders. Therefore, this pre-study has pushed the developments by gathering several inter-disciplinary experts. During 2020 and 2021 a few inter-disciplinary workshops within the project group and with other experts on competitive cycling, injury statistics, orthopedics, injury mechanisms, smart textiles, and composite materials have been conducted.

The discussion at the workshop with other experts focused on increased daytime visibility of cyclist, a key enabler to decrease the number of accidents, and new protective concept to mitigate shoulder injuries.

It is known that shoulder injuries are common, but not how a suitable shoulder protection system should be designed to be able to protect. Knowing this opens for developing garments and materials that can avoid and protect from crashes involving cyclists.

Hopefully the outcome of the pre-study will be some follow-up projects with the aim to mitigate serious traumatic injuries through a multidisciplinary approach. As there is only limited detailed evidence in the literature on cycling-related fractures, a follow-up project has already started by studying data from the Swedish National Fracture Registry, containing information from almost 600,000 fractures. The aim is to determine the location, severity, and outcomes after cycling-related fractures in Sweden from 2011-2021. This work will give important impact to remaining work on increasing visibility and impact protection in the proposed follow-up studies.

Background

In traffic safety, the safety for bicyclist is one of the largest challenges (Swedish Transport Administration 2014). Bicyclists is nowadays the road-user group with the highest number of severe injuries in Sweden and in the EU (Swedish Transport Administration 2017, European Commission 2019). There are two main challenges:

Detect cyclist: The most common accident scenario on rural roads is that the bicyclist is struck while cycling along the road (Kullgren et al 2019). Even if most of the accidents occurred in daylight conditions drivers claims that they did not see the cyclist.

Prevent the most common injury type: Head injuries account for the most severe injuries but these could partly be prevented with helmets (Rizzi et al 2013). However, the most frequently injured body region, upper extremities, are still un-protected. Most shoulder injuries (90%) occurred at direct lateral impact to the shoulder (Stigson et al 2014), which probably means that a shoulder protection could reduce the number of injuries.

Reducing injuries calls for a holistic and systemic approach. Firstly, we start from the detection problem by addressing visibility. Most often this refers to night conditions. But it has been shown that most accidences happen when a car hits a cyclist during daytime (Niska et al 2013, Kullgren et al 2019). Enhanced daytime visibility is then needed. Visibility that leads to changes in the interaction between cyclist and motor traffic by conscious or unconscious actions. Longer distance and lower speed in the situation give both parties more time to avoid incident and accidents. Identifying new concepts for increased daytime visibility was thereby a first part of the project. Secondly, when a crash occurs it is vital to mitigate the injuries. It is known *what* kind of injuries that are common, but not in detail *how* the mechanical load scenario was nor how a suitable shoulder protection system should be designed.

Knowing this enables the development of concepts for smart garments and smart textile materials. There are still no shoulder protective systems on the market that combine a comfortable design with protection ability. Previous research has led to the conclusion that it is not enough just to add soft padding to the regular cycling apparel to protect against common shoulder injuries (Stigson et al 2016). At the same time, a system must be worn in order to be protective thus offering comfort for attractiveness. This leads to the research questions:

How can we increase the ability of driver to detect and react to cyclist in daylight conditions and thereby reduce the seriousness of injuries in case of a crash?

What are the requirements on a shoulder protection system against injuries to make it both protective and accepted?

Results from the pre-study

One inter-disciplinary workshops with experts on competitive cycling, injury statistics, orthopedics, injury mechanisms, smart textiles and composite materials have been conducted to identify how modern technology can aid to decrease harmful cycling accidents. In this report the results from the workshop conducted 28th of January 2021 will be summarized. In total 31 participants from the industry Autoliv, Craft, Cycleurope, Hövding, Poc, Vasaloppet and Volvo were present. The University of Skövde and the Swedish Transport Administration also attend to the workshop. The two research questions mentioned above were discussed into separate blocks.

Theoretical Framework: Increased visibility

Visibility includes ways that enable a more distinct and earlier detection and is based on light, or more generally, electromagnetic (EM) field, as a means of doing so.

It is possible to add a systemic perspective on the traffic situation where early detection is desirable. It is in this system six key components;

I. one (or more) cyclist(s) wearing either ordinary clothes or special (biking)sportswear
II. the bike the cyclist rides on
III. a car (truck, bus, motorcycle, etc.) -driver
IV. a car (truck, bus, motorcycle, etc.)
V. a roadway
VI. there is a surrounding to the road by car and cyclist

These are in relation to each other spatially. Additionally, as in any traffic situation, their relations are dynamically changing. To note is that VI, the environment, can be as varied and complicated as is imaginable; obscuring trees and bushes in curves, foggy rain, buildings, distracting other traffic, poor or good daylight lighting and so on.

Visibility is most often associated with the bicyclist and various reflective clothing and accessories s/he may wear as well as with the interaction between the driver and his/her early detection and the cyclist, in what could be written (III -> I) but it is valuable to realize that visibility can both be affected negative and positive by and in all the *six key components* of the system. In principle, all components today can also be equipped with sensors, whereas previously it was only available in III (and I) in the form of human perception ability. Today we also talk about V-to-X where v stands for vehicle and X objects such as cyclist. All the pairwise combinations that can be formed between I to VI (15 cases) drastically increase the possibilities for improving detection. As well as also the opportunities for new solutions and innovation.

In terms of wavelength, the following distinctions can be made;
- visible area is the EM band with wavelengths in the range 380-790 nm
- radio area 1m - 10 km
- microwave range 1 mm- 1 m
(approximate limits). Humans use just the visible areas while various sensors, including different car radar systems use shorter (rarer in traffic situations) or longer wavelengths (most common, with fr example car radar in the GHz area, i.e. microwaves).

Results from the workshop regarding increased visibility
The conversations and the early draft ideas that emerged at the workshop touched on (respective key components mentioned above).

I – the cyclist's outfit
- Integration of visually invisible reflectors for the radar area in textile and thus the cycling clothing the cyclist wears.
- Working with transponders, i.e. passive elements on the cyclist.
- Study changing behavior in cyclists if they know that the cars around have sensors (and automatic avoidance systems).
- Think about including usability and user experience from the beginning when designing cycling clothing and its possible bright colors
- Have an app in the mobile phone that alerts the cyclist that the car is approaching from behind.

II – the bike

- To work with new bicycle paints for visual as well as radar detection of the bicycle and thus its rider.
- Work with transponders, i.e. passive elements on the bicycle

III – the car/truck/bus driver

- Interesting to study the attitude and behavioral change in drivers if they know that the car has sensors and all bicycles, and all cyclists have it

IV – car (truck, bus, motorcycle, etc.)

- Include aspects of biological movement related to other movements in the system of automotive sensor systems. Likewise, prediction of intention in the car's sensor system by the cyclist.

Other things that came up:

- Bring price sensitivity from the beginning in the innovation process. The difference between another sensor may not do so much in a car but much on a bicycle garment.
- Tests and standards may need to be developed. They can also be driving innovation.
- Sport can be leverage for general use in other groups, not least the prevalence of use of protective equipment.
- Different sports have different cultures regarding helmets and protection.

It can be noted that not much was said about V and VI. And as is always the case at workshops, early brainstorming exercises need to be continued to more refining phases for more concrete and forward-looking ideas. One thing that recurred, however, was whether cycling clothing is optimized (or not) for different car radar systems and the EM-fields. Maybe there was an embryo here for innovation projects.

Additional ideas for making textiles that support the detection ability of car sensors

Sensors have different characteristics as an ability to:

- Area coverage
- Angle resolution
- Distance resolution

And some:

- Range
- Sensitivity to weather conditions

Sensors are put together and data is typically merged. Different systems are then behind that:

- Detect the presence of an object (without identifying what it is)
- Locate an object at a distance and angle
- Determine an object for motion (speed and acceleration and direction)
- Classify an object
- Do scenario analysis

In turn, this becomes the basis for predicting the scenario followed by decisions such as braking, warning the driver, etc.

In the same way as for the human eye, *contrast* is a key concept for a sensor to work. The sensor needs to perceive as clear a contrast of the object to its surroundings as possible. Integrating such functionality into the textile so that the car sensors are supported is a potential project. However, the state of knowledge and need in this regard is unclear. Most of the knowledge might lie with the manufacturers of car radar systems and not be immediately available in scientific journals.

For high visibility in the visible area, retroreflection is used, see figure 1.

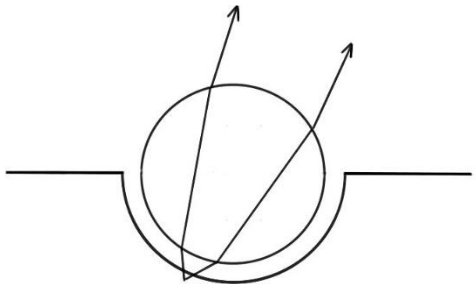

Figure 1. Retroreflection can be used on clothing to increase visibility

Small glass spheres are attached to the surface of a textile material, coated with reflective metal film (aluminum). Based on ray optics, incoming light is refracted, transmitted, refracted, reflected, refracted, transmitted, refracted so that incoming light returns in the same direction as it came in from. As the arrows shows, independently from where the light is coming in it goes out in the same but opposite direction.
This is an example of how optical properties can be integrated into textiles. A lot of new findings are emerging right now in optics and it would be interesting to look more systematically at what can promote increased visibility for different wavelength areas.

Theoretical Framework: Avoiding injuries
Head injuries account for the most severe injuries but these could partly be prevented with helmets. However, the most frequently injured body region, upper extremities, are still un-protected. Previous research shows that of all impairing injuries, almost 50% were to the upper extremities. The most common injuries to the upper extremities leading to medical impairment were to the shoulder and the wrist. Most shoulder injuries (90%) occurred at direct lateral impact to the shoulder, which probably means that a shoulder protection could reduce the number of injuries. However, the protective capacity of existing shoulder pads is small. Other design principles, such as airbags, could be a solution to obtain a higher force reduction.

All protective clothing that is sold on the European market needs to be tested and approved according to European Standard. No specific test method exists for protective clothing for bicyclist. Pads for downhill or mountain biking are tested according to the standard of motorcycle gear. This test method does not include lateral deflection of the joint and its upper force limit exceeds proposed limits for shoulder injury tolerance. Compared to other body joints like the elbow and knee the shoulder allows more deflection. The lateral displacement during an impact has been shown to correlate with the injury risk. A future test method to approve protective shoulder pads for cyclist needs to take into account the great movement of the shoulder during the impact and to identify a more relevant load case and maximum force limit.

Body gear can be made shock-absorbing material or designed to spread and distribute the force to other/bigger body regions. Here, carbon fiber reinforced polymers are often used as an outer hard protective and supportive layer to distribute localized loads, avoid penetration and excessive deformation of body parts, and to mitigate abrasive injuries. Beneath the hard cover, there is often an energy absorbing and somewhat thicker layer of a polymer foam material, with the main purpose to absorb energy and lower the impact impulse.

Results from the workshop regarding avoiding injuries
The discussion in the different workshop groups mainly discussed around the following items:

- What protective concepts can efficiently mitigate shoulder injuries when a cyclist falls to the ground?
- What kind of assessments procedures are necessary to evaluate the performance of new protective equipment?
- (Do) we need to simulate the accident, both to understand how the loads are distributed on the body, and to predict the performance of the protective equipment?
- How do we reach customer acceptance? Protection is only helpful if people wear it

From these discussions, a few different concepts to improved cyclist protection were proposed:

1. Wearable protection in the form of an airbag solution
2. Wearable protection that decrease frictional load (torsion/moment loading) to the shoulder. This can possibly be achieved by layered hard protectors, layered textiles, or protective equipment designed to delaminate into separate layers at specific loads
3. Wearable protection that protect against abrasion
4. Protection through improvements of the bike: Better breaks (ABS?), airbag or airbag-like-solutions mounted on the bike
5. (How) can we mitigate injuries by adapting the infrastructure?

Furthermore, it was concluded that, irrespectively of the protective concept, **we need to develop better test, verification and certification protocols** that are adapted for the load levels and impact conditions that are relevant for these types of injuries. These test procedures must accommodate a wide range of age, especially since the most shoulder injuries occur for kids in the age of 9-14 years. Most likely, these should in parts be based on "**virtual assessment**", i.e. we need to develop more predictive simulation models both of the human shoulder (and surrounding body parts) and of the protective equipment.
As alluded to above, we also need to work with **customer acceptance.** How do we make sure that new and improved protective equipment is being used? A few thoughts were brough forward:

1. Can elite cyclists be used as role models?
2. Can we integrate protective solutions in multifunctional clothes or other equipment that the cyclist wear also for other purposes? Here, we need to address comfort and aerodynamics

Next step after the pre-study: The pre-study directly aimed at developing increased knowledge to reduce injuries among cyclists and to transfer this knowledge to the industry. The aim was also to pinpoint new protective concepts that in the next step can be transformed into prototypes in a follow-up and larger project. The pre-study clearly showed that there is a need of addressing how smart materials and technology can be used to increase the ability of driver to detect cyclist in daylight conditions. Furthermore, additional knowledge regarding how injuries can be prevented by smart materials and products are needed. Therefore, the purpose of a proposed follow-up project is to mitigate serious traumatic injuries through a multidisciplinary approach. We will aim to reduce the number of accidents by increasing the visibility of cyclist in traffic, as we at the same time also increase the protection of critical body parts (with emphasis on shoulder injuries) when accidents do occur. At the same time, as there is only limited evidence in the literature on cycling-related fractures, we have already started a follow-up project based on data from the Swedish National Fracture Registry, containing information from almost 600,000 fractures. The aim with this follow-up project is to determine the location, severity and outcomes after cycling-related fractures in Sweden during 2011-2021. The following four possible follow-up work packages have been identified during the pre-study:

- ***WPA: Assessment of cycling-related fractures from the Swedish National Fracture Registry***
- ***WPB: Crash avoidance through increased visibility***
- ***WPC: Mitigation of injuries through improved protection***
- ***WPD: Education, dissemination, and customer acceptance***

Contribution to SAFER:
The project is a clear contribution to UN Global Goals 2030 and the Vision Zero and thereby to the SAFER's vision that all road users travel safely in the road transport system. Previous research has identified a need for improved protection for bicyclists. There is a lack of actions for protection of shoulders. Therefore, this pre-study has pushed the developments by gathering several inter-disciplinary experts, which is fully in line with SAFERs intention.

Contributions
Chalmers: Preparation and participation of workshops. Will contribute to the development of a larger grant application for the follow-up study.

Cykelcentrum, VTI: Project manager. Preparation and participation of workshops. Will contribute to the development of a larger grant application for the follow-up study.

Folksam: Provided real crash data, analysis and meetings. Preparation and participation of workshops.

Sahlgrenska Academy: Preparation and participation of workshops. Have started a follow-up project regarding fractures.

University of Borås: Preparation and participation of workshops. Will contribute to the development of a larger grant application for the follow-up study.

Vätternrundan: Preparation and participation of workshops.

Financing (in ksek): 100

Partner	**Financing Partners** In-kind	Cash	**Financing SAFER** (Cash)	**Financing External** In-kind	Cash
Folksam	51 (60 h)				
VTI			25 (25 h)		
Chalmers			25		
University of Borås			(25)		
Vätternrundan	51 (60 h)				
Sahlgrenska Academy (GU)			25		
Total	102		100		