Re-imagining motocross safety through autobiographical design

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SAMMANFATTNING
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ABSTRACT
This study explores the design space of motocross within Human-Computer Interaction with focus on warning riders of danger while practicing unsupervised. Using autobiographical design, the aim was to investigate mechanisms and modalities suitable for motocross where the environment, tracks, physical and mental load on the riders were some of the challenges faced. With basis in research within other sports and a domain expert focus group, a prototype was developed and iterated over a period of three months using the author and recruited participants as riders. The process was documented using a diary. The study concluded that using the helmet as mounting point was effective due to not being intrusive for the riders and no track alterations were needed to implement the system for real use. Visual feedback using light mounted under the visor showed to be unreliable due to sun interference, while sound created by vibrations on the top of the helmet shown to be suitable for warning motocross riders. Using visual and auditory modalities together, the light was concluded to be efficient as an information display when attention was brought to the rider by the vibration sound.

Author Keywords
Interaction design; physical interaction; peripheral feedback; action sports; motocross.

ACM Classification Keywords
H.5.m. Information Interfaces and Presentation (e.g. HCI): Miscellaneous

INTRODUCTION
Motocross is an action-filled motorsport where speed, mental toughness and physique is key to winning races. The goal of every elite motocross racer is to be the fastest around deteriorating tracks regardless of terrain, weather conditions and racing competition. At races, normally 40 riders are up against each other, while at practice sessions, the number of riders circling the track at the same time may be even higher.

The sport of motocross has evolved with more challenging race tracks, faster riders and better bikes. With time, the bike’s improved chassis, suspension and power allow riders to push the limits of how fast they can go. Motocross is dangerous by nature due to its high speeds and rough tracks. This is reflected in the research concerning motocross as it is focused around a few main topics: injuries [10, 6, 7, 3, 9], economical aspects [10] and psychology [4]. Protective gear has improved through, for example, carbon fiber knee braces as a preventative measure for serious knee injuries and helmets equipped with the MIPS brain protection system “adding more protection against rotational violence to the brain caused by angled impacts” [12].

One concern is that the safety precautions for motocross while practicing are old-fashioned. Track marshals, people placed around the track with a yellow flag, are used to warn riders whenever a crash occurs. At competitions, where track marshals are required in order to hold a competition, it works better, but at practice sessions there are usually no track marshals at all.

Within the field of Human-Computer Interaction (HCI), not much research related to motocross has been done. In contrast, other high speed sports such as alpine skiing and snowboarding have seen fair amount of research about how technology can improve technique [8, 22], by integrating technology into the helmet to augment peripheral perception [16] or explore the helmet as a wearable device [27]. Other sports such as running [18] and cross-country skiing [26, 20] have been researched on several aspects such as technique exploration, bodily interaction, play and socio-motivational systems [21].

With the author’s personal experience in motocross for nearly 20 years as a rider, this study describes an autobiographical design process where the design space in the sport of motocross is explored from an HCI perspective with focus on practice session safety. The focus of this study was to explore alternatives to the yellow flags used by the track marshals by investigating other mechanisms and modalities for warning riders taking inspiration from HCI research within other sports. A prototype was developed and tested together with end-users for investigating the possibility for an individual rider-based safety system for tackling the safety problem for practice sessions where no track marshals are available.
MOTOCROSS

Competitive motocross is a sport for all ages and is practiced at racing tracks all over the world during all seasons. The objective of motocross is to win races by being the fastest rider around the track and be the first rider to cross the finish line. Therefore, concentration and physique are essential for being fast while at the same time staying safe.

Unlike many other sports, motocross is usually practiced without trainers or defined time slots for practice sessions. Most commonly, an amateur rider decides where and when to ride, having a friend, family member or mechanic with them at the track for support and advice. Professional riders on the other hand, usually have private tracks and trainers provided by the racing teams.

Tracks, bikes & rider equipment

Motocross has a designed track to follow with man-made jumps and turns, in contrast to off-road riding, where riders ride freely around hilly terrain. For a serious rider, the ability to handle dirt, sand or gravel, which are the most common terrains at motocross tracks, is important and each different terrain requires different techniques and settings on the bike to be able to ride fast.

As motocross is practiced by all ages, there are different sizes of bikes ranging from 50cc-450cc displacement cylinder [24]. From 125cc to 450cc, the overall size of the bike do not differ considerably. The bikes are divided into two-stroke and four-stroke engines. The four-stroke bikes have a darker and louder sound comparable to a heavy road motorcycle, while the two-stroke bikes sound similar to a commuter moped. Some riders ride with earplugs to decrease the sound from the bike, as the four-stroke bikes are as loud as 112 dB when measured from 2 meters [24].

The Swedish legislation about protective gear require the riders to wear [25]:

- Helmet with mouth guard
- Heavy boots
- Chest protector
- Back protector
- Goggles made for motocross
- Knee pads or knee braces

Other countries have different legislation about protective gear. For example, riders in the USA are only required to use a helmet, heavy boots and goggles made for motocross while other equipment is only recommended, such as neck braces [1].

Track marshals

The only safety precaution system for motocross is based on the track marshals, seen in Figure 1. The track marshals are persons stationed around the track on predetermined position unique to each track. Their objective is to warn the riders circling the track of potential dangers ahead, such as a crashed rider. Warnings are delivered by waving a yellow flag or if the crashed rider seems to be hurt, a green and white flag to attract medical attention. When a rider is entering a segment with a yellow flag, the following rules apply until the danger is passed: lower the speed, prepare to be able to stop and keep both wheels on the ground [24].

Figure 1. Motocross rider jumping on a 450cc motorcycle. Behind the rider there is a track marshal at the ninth position of the track. As no yellow flag is waved, there are no obstacles for that upcoming segment.

In addition to the two flags used by track marshals, there are additional flags used at competitions which are controlled by the race officer [24].

State-of-the-art in motocross safety technology

Motocross safety systems have entered the market the last few years. All systems investigated use visual warnings in the form of lamps on the side of the tracks for warning the riders. The lamps used in these systems are battery or grid powered and are similar to traffic lights when driving a car.

Eye-Track is a recognition system for detecting a crashed rider using camera tracking [5]. The system use a device with a lamp which light up when the camera recognizes an anomaly. Another system by Brett Downey Safety Foundation [2] are controlled by track marshals using a remote control, similar to the safety system called MX1 [11]. Both systems require a track marshal to activate a segment of the track when a rider has crashed within that segment. Lamps in the beginning of the segment lights up when activated.

Movit Yellow Flag uses another approach as an accelerometer on the bike is used to detect a crash [13]. Just as the other systems presented, Movit utilizes lights on the side of the track in order to warn riders.

RELATED WORK

Research focused on motocross has not been found available in the field of HCI, while injuries [10, 6, 7, 3, 9], economical aspects [10] and psychology [4] concerning motocross has been researched.

Motocross is a potential dangerous sport which can have a large impact on the economy for the rider or family when a crash in motocross results in injuries. Studies by Larson et al. [10] and Kennedy et al. [9] focus their work on children and draw similar conclusions. Larson et al. identified all admitted injuries at a trauma center related to motocross,
both recreational and competitive, for patients below 18 years of age during 2000 and 2007. The type, severity, how the injury happened and hospital bill were assessed. 299 treatments were recorded for 249 unique patients where 184 of those cases were sustained at a licensed track. Overall, the most common causes for injuries were [10]:

- Jumping (93 cases)
- Collision (54 cases)
- Run over (13 cases)

The authors conclude that proper safety equipment and rider education classes should be taken, which is supported by Kennedy et al. [9].

Gobbi, Tuy and Meyer studied motocross and supercross injuries in Europe during a 12-year old period [6]. 1,500 injuries were analyzed where type, cause of the accident, protective gear and recovery were recorded. For professional racers, the risk of injury is higher during the start in contrast to amateur riders, where the risk of injury is higher during the last part of the race. The difference is due to the professional racers being in better physical shape and more skilled. The authors highlight that most accidents are avoidable with better equipment, riding technique, physical training or "technical solutions designed to achieve a greater degree of safety" [6, p. 18].

HCl and sports
While there is a lack of research specifically dealing with motocross within HCI, other sports have been researched from the perspective of introducing new technology to the practitioner, such as running [18], alpine skiing [28, 16], cross-country skiing [20, 26, 21] and golf [19].

Technology and protective gear
Introducing technology to the practitioner using their protective gear has shown to be successful in studies by Walmink, Chatham and Mueller [27] and Niforatos et al. [16]. Both studies aimed to use technology on the helmets to add more purpose in addition to protection. Walmink, Chatham and Mueller explored the possibility to add interactive technology to a helmet by creating a prototype where a grid of LEDs were integrated into an additional shell outside the helmet [27]. The authors used the prototype as a tool in four different ways: as a utilitarian device, support of bodily self-expression, as an artistic medium and communicating bodily data. The authors concluded that protective gear was a viable mounting platform for interactive technology as it "offer unique interaction opportunities as they are 'wearables' that are worn close to the body" [27, p. 369].

Niforatos et al. developed a prototype for minimizing the risk of collision in ski slopes [16]. The authors added laser range finder sensor to the back of the skiing helmet to detect any skiers approaching from behind, as wearing a helmet results in a significant loss in the abilities to localize sound sources [23]. Feedback was given to the user through three LEDs placed in the peripheral view of the user: two on each side and one in the center of the helmet face opening in order to warn where the approaching skier is coming from and how close by altering the intensity. The components were designed symmetrical to keep the balance of the helmet. Four main requirements were proposed for the system, where containment to prevent the device for detaching, being lightweight for preventing tiredness or injury, being safe to prevent the system from exaggerating eventual injury and ambient to allow users to focus on the slope.

Feedback and sports
To improve technique in sports, several studies have been conducted where different modalities for real-time feedback were used. In the study by Hasegawa et al., the authors explored how the center of gravity of an alpine skier can be sonificated [8]. The authors present a simple sound model based on an engine, where a lower pitch corresponds to a forward position for breaking and turning, while a higher pitch corresponds to a backward position. The volume for left and right ear corresponds to the force applied to each ski and the distortion of the sound represents the use of the edge of the ski. The authors conclude that the use of sonification for technique feedback is effective and a simple sound was appreciated.

Nylander, Tholander and Kent explores peripheral feedback in sports. The authors claim that sports could have advantages of using peripheral interaction due to general characteristics such as [20]:

- Involvement of the whole body: Visual user interfaces could be difficult to focus on due to high levels of mental focus
- Use of props: Limitations of certain types of interaction, such as holding a device while biking
- Disturbance of technology: Appreciation of the sport, meaning not needing to focus on technology

Nylander et al. investigated tactile feedback for cross-country skiing and audio feedback for golf swings. For cross-country skiing, vibrations from a cell phone equipped on the skiers’ chest was used as feedback. The signals had the same strength but different length and repetition patterns and skiers were instructed to acknowledge and comment when they felt vibrations. Post interviews concluded that the skiers did not perceive the vibrations as distracting or intrusive but experienced different strengths of the vibrations when skiing intensively or being fatigued. According to the authors, this may have been a result of athletes “block out a lot of stuff” [20, p. 3] while exercising their sport.

Research question
This study presents a design process where a safety system for motocross is designed, focusing on feedback to the rider in such a system. As clubs are responsible for the track, and the track is used by riders, both the club and the track have to be considered when dealing with a safety system for motocross. As this study focuses on the riders, the question to be investigated was: How can riders be notified/warned of potential dangers on the track?
To focus the project further, the following research question was derived from the main question: **What are suitable modalities and mechanisms for warning motocross riders while:**

1. being universally applicable
2. not disrupting the experience of riding
3. minimizing the effect on the practice of motocross
4. not being too cumbersome to implement for the tracks, such as altering the track

**METHOD**

An autobiographical design study was conducted in order to develop and evaluate a prototype including testing different mechanisms for warning motocross riders while exploring the design space of motocross within HCI. Due to the iterative nature of autobiographical design, the methodology was developed during the study and qualitative data gathering was in focus. The Double-Diamond Model of Design (DDMD) [17] was used as design approach during this study.

**Autobiographical design**

Autobiographical design is defined by the authors as: "design research drawing on extensive, genuine usage by those creating or building the system" [14, p. 515]. The methodology, commonly overshadowed by User-Centered Design (UCD) due to researchers’ fear of rejection for being less scientific, is slowly becoming more accepted in the field of HCI [14]. While data collection in UCD is crucial, autobiographical design may only document changes to the design based on the usage.

While bugs can be found and validation of a system can be done through "dogfooding", autobiographical design allows researchers and designers to expand their knowledge about the system by genuine and long-term usage while at the same time learn about the design space [15]. Genuine usage and need by the researcher is presented as a key for successful use of the autobiographical design methodology. In contrast to "dogfooding", the duration for autobiographical design is typically longer and focused on genuine usage of the system being developed. Moreover, the authors make the distinction of prototypes as prototypes evaluated in UCD may be primitive, while autobiographical design is better used with more developed prototypes with functionality implemented.

As autobiographical design do not usually have a more than a few users, the methodology does not prove generalizability [14]. Instead, it is powerful for revealing the "big effects", meaning that critical parts of the design can be identified for the design to be successful. Subtle understandings can be found during the design process which becomes valuable for the design which also makes autobiographical design reflective in its nature.

Another advantage with autobiographical design is the support of early innovation [14]. Exploratory designs where no related designs exist, the autobiographical design approach allows for learning in early stages although feedback from non-users or potential users is recommended to produce additional understanding.

**Approach**

In order to gain insight about the design space of motocross and unsupervised practicing, the evaluations were conducted in a context close to real usage. A physical prototype was iterated during the study using the DDMD approach. A domain expert group was recruited for a focus group session before the prototype development started. Only the minimal features needed were considered while more advanced features were investigated using Wizard-of-Oz methodology, such as simulating a crash using a remote control. The prototype was developed and evaluated continuously by the author and design changes and insights were documented using a test session diary. Each iteration was based on insights gained from previous test sessions.

Due to an unfortunate hand injury during one of the test sessions, the author’s ability to ride motocross was gone for six weeks during the study. A cast was needed for four weeks and another six weeks for rehabilitation. Consequently, the prototype development was frozen for four weeks while wearing the cast. Therefore, for a part of the study, end-users were recruited as replacement riders through personal contacts while the author was participating as the remote control person. The participants were not part of the domain expert group in order to include users who were not already familiar with the initial development of the system.

All test with recruited riders were conducted at Upplands Väsby Motorklubb on different days in order to experience different weather and track conditions. The participants received a brief description of the system before use and a semi-structured interview followed the test session. A consent form was used to inform riders of the risks of participating and the instructions were to ride as usual and to act as a yellow flag whenever a warning was perceived and raise one hand. A total of 12 test sessions including a pilot session were conducted where 7 sessions were conducted with the author as rider. The evaluations were conducted from March to the end of May.

**Domain expert group**

A domain expert group was recruited from Upplands Väsby Motorklubb for a focus group session in the initial stages of the study, focusing on understanding the feelings towards having technology for motocross safety from perspectives beyond being a rider. The participants were recruited through personal contacts and chosen based on their involvement within the motocross community and club. The expert group consisted of three elite motocross riders, three recreational motocross riders, two track maintainers (track crew) and one member of the board. All participants were active motocross riders.

**RESULTS**

This section describes the data collected from the test diary in the autobiographical design, the prototype changes stages and the focus group session with the domain expert group.
Initial domain expert group session
The initial domain expert group session was discussing three main topics about unsupervised practice sessions:

1. feelings towards having technology for motocross safety
2. modalities and mechanisms suitable for motocross
3. overall thoughts on the project

The feelings towards having technology for motocross safety was positive according to all involved and no direct disadvantages besides additional cost for the track or riders arose. One participant expressed that “nothing could be worse than what we already have today, which is nothing”. The same participant had experience with two existing systems, Eye-Track and MX1. When describing the systems for the track maintainers and member of the board, the feedback was that the amount of work needed to finance and implement the systems were difficult due to the work needed for placing the safety lamps, powering and maintenance. Therefore, putting the technology on the rider or bike was more welcomed by the track crew.

With the conclusion that having mechanisms on the rider to minimize the work for the tracks, modalities were discussed and concluded in using the helmet as mounting point, preferably on the visor as it is detachable and not crucial for the functionality of the helmet. As all riders wear helmets, it will always be available and the form factors are all similar. Visual feedback was considered to be preferred as all motocross riders usually have good eye-sight, however sun and mud were two factors which might lead to vision being ineffective in motocross. Discussing the issues lead to the realization that, when practicing, it is not as important to ride the entire session, meaning that if the device gets blocked by mud or even falls of, a rider can always exit the track and fix it. Sound was accepted as long as it does not require any device in the ears as some participants were using earplugs to block excessive sound while others were not positive to putting any device in their ears.

Having haptic feedback in the fingers was proposed but later rejected by some participants as “arm pump”, cramp in the forearms, is a major problem for some riders. Further discussions concluded that vibrations on the body was to be less useful due to the constant moving on the bike, vibrations from the bike and bumps on the track while riding. In particular, keeping hands and forearms free is crucial as haptic devices would require mounting somewhere along the arms or hand. One participant had tested riding with a sports watch which had the feature of vibrating at a certain GPS point to record lap times, but the vibrations were never felt by the participant.

Discussing freely about the rider based system, some participants perceived it as an “extra protection” meaning it was like buying a new kind of protective gear. There were differing opinions as to whom the protection was for: the individual or the other riders on the track. One participant expressed the problematic scenario of hitting and injuring other riders as the main reason as to why the system was useful, while other participants were more concerned about the injuries they themselves might sustain by, for example, crashing because of hitting a bike lying on the track.

Initial prototype
With base in related research, prior experience and results from the domain expert group session, the initial prototype for the rider device was made. The prototype was focused on being modular but small in order to be mounted on top of the helmet. A controller was built with the sole function of wirelessly warning the rider device, acting as a crash simulation trigger. The rider device and controller was built using Arduino compatible components and a 433 MHz radio for long range communication.

The initial feedback modality was visual and consisted of a LED strip attached under the helmet visor, strobing in yellow when warning as metaphor for the yellow flag. Figure 2 shows the initial prototype.

Figure 2. The prototype was attached on the top of the helmet and a LED strip was placed under the visor.

Pilot Test
The first evaluation was conducted at an indoor racing track due to winter conditions outdoors. When a warning was sent, the remote control person raised one hand. When a warning was perceived by the rider, the rider held one hand up and the acknowledgement was noted by the remote control person. Raising the hands allowed for both rider and remote control person to know that a warning was sent or perceived and not a false positive.

The device was not perceived as heavy or intrusive on the helmet. In the darker areas of the track, the warnings was easily perceivable although the yellow light from the afternoon sun interfered with the yellow light from the strobe making it more difficult to distinguish. A major issue was bad radio range which limited the ability to rely on the device due to not knowing if the warning was received by the rider device.

Visual warnings
Two tests were conducted with visual warnings. A white, full power light was used instead of yellow due to the visibility difficulties in the pilot test.

The first test was conducted at Linköping racing track on a cloudy but bright day. The radio range had been improved with a new algorithm for constantly streaming the warning state to the rider instead of toggling it, yielding a better range. However, this led to a drastically limited battery time for the remote control.
The white light was still hard to perceive as it was the same color as the skies and ambient light. The visor shape of the helmet used is slightly tilted upward, which made the light disappear in the environment. A methodology issue was knowing whether the rider’s device got the signals or if the rider did not see the light. Another methodology for rider and controller communication was needed.

To make the light easier to perceive, the placement of the strip was changed to the second test at Finspång racing track in sunny skies. The LED strip was lowered 5 cm from the visor end using a transparent polycarbonate sheet for the first session, seen in Figure 3. The visibility was greatly enhanced and for the second session, a black tape was placed behind the LED, creating a black border around the lights which increased the contrast to the environment. The prototype survived a minor crash and was not thought of when it occurred.

The alteration showed to be effective as the strip was not perceived to be blocking the view. The attachment was perceived as “see-through” and the light was easier to perceive in direct sunlight. This test session also focused on improving the methodology. Each lap had one simulated crash, randomly selected by the person in control of the remote but in a way that the remote control person could see the warning in the rider’s helmet. When a warning was perceived by the rider, the rider were to slow down as the rider would if it was flagged yellow and when passing the person holding the controller, the rider would raise the hand if feedback was perceived, marking it on a piece of paper. All 5 warnings sent by the controller person was acknowledged by the rider.

The methodology was more successful as counting the perceived warning given was possible. Although, only having one simulated crash for each lap was limited due to the few laps managed to put in in the limited time of the session. Therefore, the limitation of one simulated crash per lap was removed and instead the remote control person would simulate a crash randomly when it was easy to see whether the rider’s device got the signal and mark on a piece of paper if the rider acknowledged the warning by slowing down.

**Auditory feedback by buzzer and an unfortunate accident**

In addition to the visual feedback, a high-pitch buzzer sound was added to the rider device as shown in Figure 4. Due to hardware limitations of power limited to 3.7 Volt and the closed encapsulation of the prototype, the sound was not very loud while the device was attached to the helmet during simple attachment tests without the bike.

During the first test of the updated prototype at Arlanda racing track, a rock caused a metacarpal fracture in the authors hand and a crushed knuckle. For the following test sessions, the author took the role of the remote control person and recruited riders to stand-in as participants in the evaluations of the prototype as described earlier.

The first test was done with a former elite rider riding a four-stroke 450 cylinder bike in cloudy but light conditions in the forenoon. The device was not considered intrusive and was not disturbing the experience of riding. “I did not notice the device by extra weight or anything like that and the lamp was placed so high that I did not think of it”. The sound was not perceived, but the visual feedback worked as all 12 warnings caught the rider’s attention. “It was nice to feel like someone was watching over me” was expressed after the test session and the overall attitude was positive.

The second test was done with a recreational rider riding a two-stroke 250 cylinder bike in a morning with sunny skies. The device was not considered intrusive and both visual and auditory feedback was perceived, although the auditory feedback was best heard while breaking as the engine is the least noisy at that point. All 14 warnings were caught by the rider. “At one moment, I thought it was blinking but it was just a sun reflection in the transparent material. I just looked up to
A small vibration motor was added to the prototype, as shown in Figure 6. The initial vibration pattern was vibrating on and off for 0.2 seconds. To prevent dust and water to enter the exposed component, the vibration motor was taped down to the helmet using electrical tape.

Figure 6. A small vibration motor was added to the prototype.

As sound by vibrations should help the riders from visibility issues, the test was conducted an evening when the sun was low. The participant was a recreational motocross rider, riding a four-stroke 350 cylinder bike. Before the test began, the parts of the track where the sun was directly in the eyes was identified.

All 15 warnings were detected using the light, but the vibrations were not heard or felt at all. The overall experience of the device was positive, as "it was a little unusual the first couple of laps, but then I did not notice I had it on me". As one earlier participant pointed out, sun reflections in the plastic holder was perceived as a warning, but was confirmed false by glancing at the light. "I think the light could be a problem in the sunlight conditions we had today". One problematic scenario discussed was when the sun is directly in the eyes for a longer period of time, the need for instant reaction may be crucial to avoid an obstacle. At the test session, there were no parts of the track where the sun was interfering for more than about a second, which might be the case for different tracks.

The second vibration test was conducted with the earlier, former elite participant who tested the visual and auditory warnings. While the previous test showed that the vibrations were not perceived, the vibration motor were now vibrating freely and was more "hitting" the helmet, rather than vibrating similar to a mobile phone on a table. This showed to be efficient and all 10 warnings were perceived where the vibrations were acting as primary warning. "I knew what to listen for, and I would rather do that than looking at the light. I do not know why, it was just better". The participant expressed that it was harder to see the light this time. This time, reflection in the LED attachment was triggering false positives but were rejected by the rider due to no sound from the vibrations were heard.

**Final test sessions**

Being back from injury, the author did three more test sessions with focus on verifying and understanding the feedback given from the participants. The first two tests were conducted together with former participants in order to document their feedback on the changes to the prototype.

The first session included an evening test session where the sun was clearly disturbing the riding. The session was conducted by the author with two changing variables based on insights: with and without earplugs, riding a four-stroke and two-stroke bike. No difference in warnings was perceived for vibration sound as the vibrations were heard clearly for all different setups and acted as primary trigger for all warnings. A recurring pattern for warning was detected: hearing the vibrations, then glance at the visual feedback for confirmation. The sun reflection in the LED attachment were more severe in this setting than prior experiences by the author, as this extreme sun conditions was not tested earlier with the author as rider. The difficulties were especially prominent when the sun was shining through trees, which made the reflections appear similar to the visual warnings with a strobing effect. This made the visual feedback feel unreliable in this environment setting making it feel untrustworthy.

The previous participant riding the two-stroke bike tested the prototype and thought the sound by vibrations were better than only the light as it was more distinctive from the en-
In this study, the design space of a safety system for unsupervised motocross practicing was explored using autobiographical design with focus on suitable warning mechanisms and modalities for rider warnings. Discussions about the prototype, modalities evaluated and methodology are presented in this section.

**DISCUSSION**

In this study, the design space of a safety system for unsupervised motocross practicing was explored using autobiographical design with focus on suitable warning mechanisms and modalities for rider warnings. Discussions about the prototype, modalities evaluated and methodology are presented in this section.

**Interactive technology on helmets**

As earlier research concluded, adding interactive technology to protective gear was shown to be efficient. Similar to Walmink et al. [27], the technology on the helmet in this study was used successfully as a utilitarian device. In the case of a safety system for motocross, it was not only efficient for the riders, it also solved one of the underlying problems with the cost and need to alter the track for the existing safety solutions.

As motocross aligns with the characteristics of a sport with advantage of peripheral feedback presented by Nylander, Tholander and Mueller [20], mounting the prototype on the helmet allowed for experimenting with such feedback. This showed to be a viable placement for technology for motocross as no participant perceived the prototype as intrusive or disturbing as no new props or change in the riding style was needed.

One concern which occurred during the evaluation of the prototype were the impact it could have during a hard crash. As in the requirements proposed by Niforatos et al. [16], a helmet mounted device must be safe and not exaggerate injuries. While the prototype was used for only one minor crash in this study, it is not possible to conclude whether the prototype may exaggerate injuries. An alternative would be to integrate the device into the helmet, but as the prototype should be universally applicable, integrating it into helmets would complicate the installation.

**Modalities**

The modalities were explored to the extent that insights about the context usage could be drawn and revealing the "big effects", which was why autobiographical design was chosen as methodology. Each modality could be explored further, but as this study was limited in time and was focusing on exploring the design space, this was not done.

**Visual warnings**

While visual feedback was the preferred modality during the expert domain focus group session, it proved to be problematic. Not only does it add an installation complication to the prototypes universal applicability, it had reliability issues when the sun was directly in the eyes. As all warnings were perceived during the evaluations with the visual warnings, it proved to be effective but unreliable. Moreover, as the visual feedback was unreliable in the more severe sun conditions, it may not be suitable for warnings in motocross as trust is a vital component for a safety system. Furthermore, visibility issues could also affect the reaction time in the event of a crash. As researched by Larson et al. [10], collisions and being run over is a common source of injury for motocross riders. In the event of a crash happening in a part of the track having sunlight issues for the riders, it might lead to a severe crash if the riders cannot perceive the warning fast enough.

**Auditory buzzer warnings**

The audio feedback by buzzer was considered not be effective as the four-stroke riders did not hear the sound at all. Although the idea of having audio as feedback showed be efficient as the sound by vibrations proved, it could in this case.
be a result of hardware limitations which is why the continued investigation of sound by buzzer was not proceeded. A more powerful buzzer might have been easier to perceive for the four-stroke riders as the two-stroke rider did hear the sound.

**Auditory vibration warnings**
While both the visual warnings and auditory warnings by buzzer showed to be problematic, the sound by vibration warnings solved most of the problems. As the vibration motor was attached close to the device, extra cables or attachments such as the LED strip was no longer needed which would simplify installation. The vibration sound also provided near instant warnings leading to perceived faster reaction times and therefore a safer system. As one rider expressed, knowing what to listen for was positive as the risk for false positives, such as the reflection in the LED attachment is diminished. The advantage over the visual feedback is that the reaction from only visual feedback could be delay due to difficulties seeing the warning in direct sunlight.

Additionally, the vibrations did minimize the need for focusing on a visual interface. This was described by Nylander, Tholander and Mueller [20] as one of benefits for using peripheral feedback. When the mental focus is high, peripheral feedback has advantages. This agrees with the results gathered from the vibration sound tests as the vibration sound became the primary trigger and was considered better by both the author and two test participants due to its distinctive sound and instant warning. As Nylander et al. described, athletes “block out a lot of stuff”, which in the case of motocross could point to more focus on visual senses as focus lies on the track ahead rather than the sound of the bike. This would explain why auditory feedback were more suitable as it is a peripheral feedback. Encapsulating the vibration device would also solve the problem with rain and mud, as visual feedback might be blocked due to mud thrown by other riders. As the prototype was not weather-sealed, this condition was not tested due to the risk of destroying the device.

**Warning for attention, not information**
An interesting insight found in this study was with how accurate a warning might need to be for a safety system for motocross. As in Niforatos study, the ski helmet warned from where and how close the approaching skier were [16]. In the case of motocross, a common problem is the concentration of the track right in front of the rider. A warning which simply makes the rider look up and do a quick scan of the upcoming track segment could be sufficient to know that something has happened, somewhere and caution is needed. Furthermore, this means that the feedback could be simple and limited to one dimension. This agrees with how the existing track marshal warnings are provided with the yellow flags: as a rider you only know that something has happened and you look for the obstacle the instant you see the yellow flag.

On the other hand, the three last test sessions showed another interesting insight. By using both sound by vibrations and visual feedback by light, an information layer could be achieved. By using vibration sounds as main trigger for attention, the rider can glance at the light in order to get information about the crash. For example, the light could be shown in yellow on the left side of the LED strip if the crash has happened on the left side of the track, or the competition flags could be implemented.

**Expanding on light as informative feedback**
When injured, the author took the role as the remote control person which focused on simulating crashed for the participant. As using vibration sound as primary trigger was concluded to be most effective, the visual feedback could be removed, although expressed to be useful by some participants. With this in mind, the visual feedback could have other use cases. For serious riders, taking lap times in order to know how fast you are in relation to other riders are commonly done during practice session. Using the insight about light as information display, the system could be used as a utilitarian device to, for example, increase the experience of riding motocross with feedback for each lap time. Adding an accurate GPS unit to the rider device could be used to give feedback for lap times to the rider. As there is only one finish line on the track, the rider will know when a lap is completed. Using the visual feedback for indicating how fast the lap was, green light could be used if the lap was faster than average and red if not, would create an implicit interaction with the finish line. In addition to increasing safety for unsupervised practicing, the system might also be useful for an aspiring rider wanting to become faster.

As the visual feedback using light showed to be problematic in difficult sun conditions, changing the main purpose of the light from warning the individual rider, to warn others might be a better fit. As the main existing warning mechanisms for motocross are the yellow flags, using the prototype developed in this study would change the way warnings are delivered: from universal warnings to individual warnings. An interesting solution would be to equip the rider device with flashing lights behind the device, aimed towards the riders behind, thus allowing the new system to include a universal warning system too, shown in Figure 8. Using a GPS unit, the track could be divided virtually into segments. If a crash can be detected in a particular segment, a rider can get a "heads up" warning by the rider in front, just as a brake light works for cars in traffic.

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**Figure 8. Proposed prototype using visual feedback for riders behind, visual feedback for information and vibrations as primary trigger.**
Data collection

This study focused on qualitative data gathered from test sessions using the autobiographical design methodology. Quantitative data was considered secondary due to the reflective nature of the method. As the study showed, the quantitative data gathered by counting the acknowledged warnings, showed little insights. All recorded warnings were caught by the riders, but the qualitative data showed that some mechanisms such as sound by vibrations were more efficient that visual feedback by light.

Quantitative data in this study could have been gathered using a more complex and developed prototype for measuring data concerning the warnings. One concern which was apparent during this study was the delay between the warnings sent to acknowledgement, but as hardware issues and radio range was not focused in this study, more simplistic measurements was used.

Exploring a design space using autobiographical design

While the study was unfortunately interrupted by the injury sustained during testing, the methodology showed to be effective in an unexplored design space. As Neustadtter et al. [14] describes, autobiographical design showed to be a powerful methodology revealing the "big effects" and support of early innovation. This study showed that edge-cases for the particular design space was found effectively. For example, moving the LED strip down 5 cm showed to be effective for the problem of direct sunlight, but visual warnings were later concluded to be unreliable due to reflections in the LED. The reflection problem, which were caused by weather conditions not tested until the later stages of the study, might not have been found using a common usability test conducted over one or a few days. As weather is one of many factors in motocross, known through the authors own experience, the key to a successful exploration of the design space was the long duration of the study. The longer duration allowed for several iterations and diversion within the design space, which worked well due to the essence of the author’s knowledge in motocross and interaction design. Hence, ideas could quickly be invalidated by test sessions or prior experience by using the author’s design judgment.

One might think of the methodology in this study as an autobiographical design by proxy, as the prototype was tested by the author and recruited participants. The genuine use of the prototype by both the author and participants showed to be efficient as the author was able to test the prototype long enough for understanding what the participants would be faced with during a test session and therefore being able to ask questions raised during the author’s test sessions.

On the other hand, the participants during this study were faced with unusual technology for motocross which might have biased their way of riding as they knew that a warning might come. Although, this is the real scenario, the simulated crashes might have led to more focus on the warnings than would be the case in real use: warning only when a crash occurs.

Future work

Using the final prototype in this study, a new way of triggering the device would be interesting future work. While not being able to ride, insights were gathered about how crashes could be triggered which showed to be a challenging issue. The motocross safety systems available have two main affordable means of triggering a crash: by a remote control [2, 11] or automatically using an accelerometer [13]. While the author was acting as the remote control person, difficulties arose while following a person closely, such as the ability to detect crashes in front of the rider was not reliable due to the focus on the rider being followed. Automatic triggers using for example an accelerometer would be advantageous, similar to Movit [13] but attached to the rider device. On the other hand, there are several cases which were detected, such as a rider stopping by the track to fix the equipment or a faulty bike which might be difficult to detect automatically. Therefore, both a remote control, for example a smartphone application used by selected audience, could be used together with an automatic trigger in the rider device. The human interaction with the system might give additional trust to the riders. As one participant mentioned, “It was nice to feel like someone was watching over me”. Another resource which could be used as crash trigger are the other riders. If each rider would have the ability to trigger warnings, the simpler yet difficult cases which need warnings would be diminished by creating rider-to-rider warnings.

CONCLUSIONS

The mechanisms found to be most suitable for warning motocross riders of danger while riding unsupervised was sound made by vibrations on top of the helmet. Using the helmet as mounting source was not considered intrusive and allowed for different modalities to be explored. Additionally, the need for major alterations to the track or the riders was not needed using the prototype. This systems is a promising candidate for increasing safety for unsupervised motocross riding.

The universality for the warnings using sound by vibration was perceived as most effective, as it solved most problems with external conditions such as weather and other riders in comparison to visual feedback using light and auditory feedback using a buzzer. For visual feedback, difficulties occurred in specific light conditions as the sun interfered with the light source and the sound by buzzer feedback was difficult due to the sound of different bikes used in motocross.

Designing and developing a prototype using autobiographical design methodology was considered successful. This study agrees with earlier benefits described with the methodology as it allows for innovation and focus on revelation of the "big effects".

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