Masks For Sports

Development project of protective respiratory masks for ice hockey teams during the COVID-19 pandemic

Report

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HELPFUL
An Initiative by the ETH Domain and Swiss academia

Helpful-ETH Project: Mask for sports

Development project of protective respiratory masks for ice hockey teams during the COVID-19 pandemic

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Abstract

High infection numbers but also a massive uncertainty because of the COVID-19 pandemic put high pressure on the healthcare sector and led to severe restrictions in daily life. In order to support societal and medical needs, the voluntary HelpfulETH initiative supported the healthcare sector with solutions. HelpfulETH provided and coordinated technological development also by managerial assistance. The chosen project portfolio also comprised the sports industry, as a cornerstone of societal expression and enjoy. The hereby reported project concentrated on finding a solution to counter the massive impact of COVID-19 infection in ice hockey.

With the government introducing distance and hygiene regulations to reduce infection numbers, ice hockey competition was suspended and training interrupted, at the beginning of the pandemic early on. Countering the pressure and the uncertainty created by the immediate lock-down in the sport, this project pursued a fast-track development of a protective respiratory mask tailored to ice hockey.
The project defined the requirements of protective gear gathering the information from athletes but also experts in the sport, in medicine and in virology. As project results, commercially available respiratory masks were not found suitable for sports, hindering the breathability and performance of the athletes. In search of a solution to meet the complex and very exigent needs, an anesthetic mask combining existent components such as a viral filter showed better suitability. Testing a realized prototype, further research and design needs were identified to allow respiration in this professional and demanding sport.
A continuation of the development in regards of a possible second infection wave or future pandemic following a regular product development procedure, could build on the project results and the identified needs to consider a solution favoring active air support or further reducing the air resistance of the filters by reducing the viral protection.

Table of Content

1. Introduction

1.1. Background

During the COVID-19 crisis starting in Switzerland in March 2020, healthcare was put under high pressure due to rising infection numbers. Effective short-term engineering solutions were needed to deal with shortages in medical supplies and other arising problems. The HelpfulETH initiative from ETH Domain and Swiss Academia, was formed to support those needs with voluntary teams working on solutions for specific challenges.

Affected by the pandemic crisis, professional sports were interrupted. This also affected the Swiss ice hockey league. All teams faced an unknown and uncertain future due to the ongoing CVOID-19 pandemic situation leading to challenging restrictions taken by the Swiss government. The interruption affected the league events and matches but also training within the teams.

A HelpfulETH-project was commenced to develop solutions for protective equipment, to avoid COVID-19 spreading between ice hockey players, in order to resume training and competition.

1.2. Evolution

After the Swiss government declared the "exceptional situation[1]" due to COVID-19, public life was shut down to slow down the number of infections and reduce pressure on the healthcare system. Shops were closed, events were cancelled and so were sport facilities and matches. Within a very short time, training was limited and only possible individually at home. These measures imposed a difficulty for ice hockey teams to prepare for future competitions and to keep the team able-bodied and orchestrated.

The situation changed constantly during the COVID-19 pandemic and government measures were subsequently adapted over time. Whereas the situation relaxed after the sudden and far-reaching shut-down, a slow resumption of sport activities took place, however the future evolution remained uncertain. Research and development for protective equipment was pursued until the "exceptional situation" ended in Switzerland.

Governmental decisions impacting sport were the following:

1. 12th March 2020: Swiss Ice hockey suspends trainings and competition
2. 16th March 2020: Swiss government declares "exceptional situation"
3. 11th May 2020: Sport trainings allowed under strict hygiene rules, following distance regulation and allowing only up to 5 people
4. 6th June 2020: Sport trainings of any sort allowed with only few restrictions Competition possible only for non-contact sport
5. 19th June 2020: Swiss government left the "exceptional situation".

The most secure step to resume trainings and competition was perceived with the development and production of a suitable protective respiratory mask. A quick but reliable development of such a mask built the main goal of an according project that was initiated by HelpfulETH starting 23rd of April 2020. In this context, the "extraordinary situation" allowed for a fast track development of products and solutions.

Over the time span of the project, the situation relaxed and at the time of this publication - in June 2020 - ice hockey and sport activities in general were allowed without further restrictions. Due to the revocation of the "need of urgency" of the product, the fast track product development ended and the design of this type of mask requires a long-term project with testing, going beyond the scope of the HelpfulETH initiative.

With eventual risk of a second wave of infections or a new pandemic in the future, the outcomes of this project can serve as a starting point for future development of protective respiratory masks for sports.

[1] Schweizer Bundesrat; *Verordnung 2 über Massnahmen zur Bekämpfung des Coronavirus (COVID-19),* March 16th 2020

1.3. Motivation

Professional sport leagues were searching for concepts to resume competition and training. Whereas some concepts opted to mainly focus on refraining from public interaction, e.g. the German professional football league resumed their ongoing season without spectators at an early stage in line with intensive testing and strict hygiene rules, the uncertainty of the pandemic evolution asked for more comprehensive measures.

In order to avoid virus spreading and to minimize the athletes´ health risks, protective gear was sought for. Indeed, ice hockey - as an extreme form of contact sports - required far-reaching protection and regulation. Any solution needed testing as well as cost assessments in order to be considered as potential sustainable solution.

The ZSC Lions Hockey team intended to properly deal with the COVID-19 situation from the beginning. The development goal of a protective equipment solution was embodied in the HelpfulETH-project. The team's request and vision for protection of their athletes to significantly reduce infection risk was the guiding principle of the project. The project intend was declared in developing a mask to be worn by all players, in the aim to realize a seamless and fair resumption of competition, but also trainings in the first place. Starting with the intended use defined by the team, a market research of suitable solutions lead to producing a first prototype being tested to finalize a product.

2. Challenges

The SARS-CoV-2 virus is distributed mainly by aerosols, which are breathed in. This makes respiratory masks the first and most important protective equipment to start contact sports again, where it is not possible to keep safety distances.

The main disadvantages of respiratory masks in sports are the potential negative effects on the athletic performance. Commercially available masks are in this context not suitable for a competitive performance as essential performance factors like breathability and the field of vision are reduced significantly.

Hence, the project was launched to create a specific mask for ice hockey players, given specific requests in regards to breathability, sweating, oxygenation, durability, hydration, contacts with opponents etc. The development of respiratory masks needs to take challenges set by ice hockey into account while providing sufficient viral protection. Subsequently, the development of such a mask asked for an interdisciplinary team. The team was staffed by volunteers from ETH Zurich and integrated in the HelpfulETH efforts. User needs were constantly considered and updated during regular meetings with representatives of ZSC Lions ice hockey team. In order to counter the challenge of uncertainty in regards to the virus a virology expert was integrated in the project as well.

2.1. Respiratory Mask

There is a large range of respiratory masks available, using different methods and materials to filter particles from the air. SARS-CoV-2 limits the applicability of these masks. The small size of about 100nm of the virus makes it difficult to filter.[2] That reduces the number of suitable masks and filter materials for our intended use drastically.

Generally, two types of masks were used in the pandemic, seen with variations in figure 1. The first ones are FFP2 and FFP3 respiratory masks, the others simple face covers like chirurgical masks.

Chirurgical masks are loose and provide only rough protection against the virus, clearly offering not enough protection as demanded in this project. FFP masks were originally intended as workplace protection against dust and nanoparticles hence also offer a high protection against breathing in SARS-CoV-2. The difference between FFP2 and FFP3 masks lies in their filter efficiencies, but generally both are suitable against the virus. They were used in hospitals and other essential workplaces where distancing cannot be followed. The main disadvantage of those masks is a significantly reduced breathability, that makes it unsuitable for any form of competitive sport. Ventils can help making breathing out easier but increase the risk of infecting others. Such ventils leave either inhalation or exhalation unfiltered.

The viral protection aspired in this project was of the order of FFP3 masks, having a filter efficiency of around 99%.

Figure 1: "DACH" Respiratory masks: From top left to bottom right: surgical mask, FFP2 without ventil, FFP2 with ventil, FFP3 with ventil. [3]

2.2. User Requirements

Sport specific requirements significantly limit the freedom of design. In the case of ice hockey, the face mask should be integrated into the standard protective equipment already in use. Many factors of the athletic performance are not compatible with a face mask. A suitable design needs to address the players' requirements without compromising the anti-viral effectiveness of the mask. With extensive feedback by the professional ice hockey players of the ZSC Lions, essential requirements of the mask were identified as follows:

[2] Y. Bar-On, A. Flamholz, R. Phillips, R. Milo; *SARS-CoV-2 (COVID-19) by the numbers*; eLife Sciences 9, March 2020

[3] DACH Schutzbekleidung GmbH & Co. KG, Products

Respiration
Filters impose an increased air resistance on the air flow. The natural resistance of the respiratory system is 3 mbar l/s with respirator masks adding an additional 1-15 mbar l/s[4]. The effect of the mask is not negligible, becoming a limiting factor in the mask design.
The breathing effort in case of a membrane with high resistance increases exorbitantly. As a result, the athletes' performance with reduced oxygen supply is drastically reduced[5].

Additionally, air scarcity can provoke claustrophobic anxieties. Resulting panicking can pose a threat to athletes. The athletes´ respiratory systems pose additional design challenges:

- athletes possess maximal lung volume and more air needs to pass the filter with every breath,
- the breath rate is increased during sport efforts compared to resting activities,
- airflow is stronger as more air needs to enter the lungs in shorter time.

Every of the above factors is hindered by the increased air resistance of masks[6]. For hockey players it is crucial to ensure the oxygen supply to keep up their muscle function.

A larger air volume inside the mask requires more effort such that the air gets exchanged and carbon dioxide cannot accumulate inside the mask. Reducing the dead volume of the mask as well as the air resistance is crucial to allow breathing when wearing a mask.

Moisture
Strong breathing, rapid movement, contact and sweat lead to moisture accumulating inside the mask. This moisture can heavily affect the functionality of the filter[7,8].

Sight
Ice hockey player strongly rely on their surrounding field of vision, to keep track of the puck and of other players. The mask geometry must take that into account.

Movement
Ice hockey is characterized by intensive body contact as well as movement. A comfortable and sealing fit of the mask is required reflecting the need for agility and physical contact.

Temperature
Ice rinks have strong temperature gradients. To ensure visibility and functionality when wearing the mask, it is important to protect the mask and equipment against fogging.

Disinfection
A used mask must be considered as contaminated. To prevent a spread of the virus through used protection materials, all components must be either exchangeable or disinfectable.

Equipment
The respiratory masks should comply with other protective equipment worn by the athletes. The size and geometry should fit the helmet and the mask must not provide a threat to safety.

Drinking
Water supply is important and necessary during training and competition. Removing the mask covering the mouth poses a high risk of getting in contact with the virus.

Communication
Communication during the game is important for the athletes. Masks strongly hinder not only the airflow but also the sound, making it hard for athletes to communicate during the competition.

2.3. Consequence

Respirator masks, to be applicable in sports, need to comply with a range of features that should be optimized and part of a solution, the breathability posing a critical point should not be compromised. The focus of the development hence lied on getting reliable feedback on the breathability of the mask prototypes.

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[4] T Urbankowski, T Przybyłowski; *Methods of airway resistance assessment;* Pneumonol Alergol Pol. 84(2): 134-41, 2016

[5] D. M. Caretti, W. H. Scott , A.T. Johnson , K. M. Coyne & F. Koh; *Work Performance when Breathing Through Different Respirator Exhalation Resistances*; AIHAJ - American Industrial Hygiene Association 62:4 411-415, 2001

[6] R. G. Bartlett, H. F. Brubach, R. C. Trimble, H. Specht*; Relation of Increased Airway Resistance to Breathing Work and Breath Velocity and Acceleration Patterns with Maximum and near Maximum Breathing Effort*; J. Appl. Physiol. 13(2): 194-204, 1958

[7] R. J. Roberge, E. Bayer, J. B. Powell, Aitor Coca, M. R. Roberge, S. M. Benson; *Effect of Exhaled Moisture on Breathing Resistance of N95 Filtering Facepiece Respirators*; The Annals of Occupational Hygiene, Vol. 54, Issue 6, August 2010

[8] J. D. Newnum; *The effects of relative humidity on respirator performance*; MS thesis, University of Iowa, 2010

3. Materials and Methods

Considering the time pressure of creating a solution, the project team decided to pursue an analysis of commercial solutions, potential adaptation of existing masks, and a design and creation approach.

After having gathered all requirements from the user's perspective, the team jointly concluded after a screening of existing solutions, that commercially available respirator masks provided no viable solution. The complex and specific requirements for a mask for sports can only be reflected in a tailored design and development, in order to fulfill the needs of ice hockey athletes.

In the course of the project, research and development considered existing solutions not only as entire but also as potential component part of a quickly designed solution.

3.1. Commercial sport masks

A range of options is available on the market to assemble a mask for sports The existent masks or components can provide a reasonable starting point for a design and development of a viable solution, however the compliance with viral safety standards is not sufficient. The solutions described in the following are shown in figure 2.

Ice hockey full face masks

Ice hockey helmets normally have only a small visor over the eyes for protection against mechanical impacts. Helmets covering the whole face are available, though rarely used. Sealing the helmets with filter materials could provide viral protection. Still, large volume and fogging problematics pose difficulties.

Sport respiratory masks

Sport-specific masks to filter invasive particles have been developed for sports like cycling or Enduro biking. These sports deal with air pollution or dust and use masks to protect the lungs. Built from neoprene material, they can deal with moisture and sweat. Some masks also provide basic safety against bacteria and viruses, not reaching the efficiency aspired to protect against COVID-19.

Air mask

Out of the context of viral safety other masks have been designed for use in sports, addressing the factor of breathability. One such solution is the "Airtrim" mask that protects athletes from cold dry air, as developed for cross-country skiing. A special filter heats and moisturizes the air in the breathing process.

Figure 2: From left to right: Ice hockey full face mask, cycling dust respiratory mask, "Airtrim" air mask.[9]

3.2. Prototype structure

In lack of a commercially available solution for a respiratory mask, a newly designed mask needed to be created and assembled. A first prototype was designed combining a standardized medical mask and an air filter. This design allows for choosing the components to match the requirements set by ice hockey. Figure 3 and figure 4 illustrate the created composition of a simple mask, filter, and mount with fasteners to fix the mask to the head.

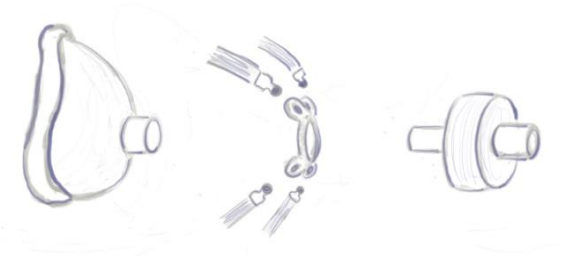

Figure 3: Prototype components: A simple mask is combined with a filter and hold to the head with a mount and straps.

The components were selected prioritizing simplicity and ease of product development during COVID-19 situation. Combining CE-certified products reduces the inherent risks of prototyping with not proven components. The resulting prototype allowed for first simple real-life tests to check the utility for ice hockey with a focus on breathability.

[9] BAUER Hockey LLC, Products; SKYSPER., Products; Vapro Produktutveckling AB, Airtrim andningsmask

3.3. Components and materials

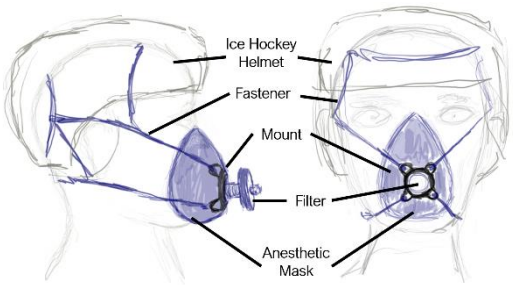

Figure 4: Sketch of the composed prototype mask as part of the ice hockey protective equipment.

Medical mask

Surgical masks filter with cloth layers. Such a design is insufficient for sports as the masks cannot deal with moisture. Other medical masks as shown in figure 5 were considered to be useful as they comply with medical standards and are disinfected easily.

Anesthetic mask: Built out of silicone they allow a good fit to the face. Softness is important to prevent injury due to body contact.

Spiroergometric mask: In spiroergometric test for athletes a mask with large breathing volume is fixed to the head and breathing parameters can be measured.

Of the two existent solutions, anesthetic masks were favored and implemented into the prototype as they meet the needs of comfort but also respiration.

Figure 5: Medical masks: Anesthetic (left) and spiroergometric model (right). [10]

Filters

A wide range of air filters with different concepts are available. The filters were tested and certified in regards to viral safety and therefore protectivity information was accessible. For sport masks, the filters with low air resistance and little moisture impact are more suitable. Filters work either mechanically (small mesh size) or electrostatically (capturing the charged virus particles). As a result, filter types depend on the material and mesh size.

Mechanical filter: Mechanical filtering works by restricting the flow of small particles through small mesh sizes. This process normally requires multiple layers of material, increasing the air resistance.
Electrostatic filter: Electrostatic filters are composed out of slightly electrostatic materials which ionize the aerosols and capture them in the material. These filters generally rely on fewer layers and offer less air resistance[11].

Meeting the criteria of simplicity, existing filter for anesthetic systems were selected for an initial test in further prototyping. Two filters with high viral repellence and low air resistance were decided as optional components in the prototyping. Those were the following electrostatic filters from Dräger[12]:

- Dräger CareStar 30: 99.99% virus repellence, up to 1500ml tidal volume, 3.9 mbar l/s resistance at high air flow
- Dräger TwinStar 55: 99.99% virus repellence, up to 1500ml tidal volume, 5.3 mbar l/s resistance at high air flow.

Mount

In the course of designing prototypes the fastener straps from the spiroergometric set-up provided a strong but still comfortable fixation of the mask to the head during movement. To make use of these straps, an adapted and specific mount for the anesthetic mask was designed (see figure 6). The first model of the mount was printed with PLA for a proof of concept. For competition, 3D printed parts will not be suitable as they can't hold reliable during contact.

Figure 6: Mount aperture in a 3D CAD design.

[10] MEDAS Inc., Products; DYNOSTICS Sicada GmbH, Products

[11] S. Varnaitė-Žuravliova; *The Types, Properties, and Applications of Conductive Textiles*; Cambridge Scholars Publishing, p.22, 2019

[12] Drägerwerk AG & Co. KGaA; *Filter/HMEs: Unterstützung der täglichen klinischen Routine*; 2017

3.4. Testing

After the prototype design, a first impression on the performance through a simple test was realized. This first trial was performed together with a project member - who is a professional hockey player for the Zurich ice hockey team. The athlete analyzed the mask in a training atmosphere in the ice rink giving a qualitative assessment on the breathability impact of the mask and other insights on comfort and visibility were collected.

A quantitative test of the mask functionality in form of a study requires an extensive and intensive testing performed on humans. Such process needs approval and support by the swiss ethic committee. This approach safeguards of risks by the use of the mask. As a result, the testing only provides first and preliminary insights indicating a suitable functionality of the mask. Further testing with the ZSC Lions team integrating the ethic committee is envisioned.

4. Result

Figure 7: Pictures of the assembled prototype how it should be worn with the helmet

The project with the ambition to create a COVID-19 protecting mask for ice hockey players resulted in the design and assembly of a prototype shown in figure 7. Design components mainly consist of CE-certified parts. A prototype testing resulting in first impressions on comfort and functionality was realized with one voluntary proband as a very simple and basic test by the integrated ice hockey team to probe the components on the applicability in sports.

4.1. Functionality test

The test indicated that the designed and developed prototype can serve for further design studies. Breathability was identified as the prime factor for mask utility. Filters are core components in the design of the mask, however they currently represent the bottleneck for comfort and usability.

Respiration

For both filter systems, the breathing process was impeded strongly. As main insights can be concluded:

1. Air filters protecting in both directions are not suitable for any sport activity as the oxygen support is drastically decreased.
2. The inhalation process is stronger affected by the mask than the exhalation process.
3. The volume inside the mask is too big to allow for a complete air exchange with increased breathing rates.
4. The difference in air resistance between the air filters was detectable already in the first and rather simplistic tests.

General remarks

The developed prototype met the requirements of easy assembly and disinfection handling.

The silicone mask proved to be seal and comfortable. The designed mount and fastener straps provided a sufficiently secure hold during movement. Still, the mask would require further protection to hold in case of hard body contact between players.

The prototype tests did not suffer from fogging. Apparently, this design and large filter had a negative impacted on the field of vision. Mainly, the downwards vision, which is important to control the puck, was affected. However, the mask size proved sufficiently small to be used with protective hockey gear. The straps on the back of the head were slightly irritating in combination with the helmet.

Drinking might force frequent removal of masks and causes a high exposure risk. Touching the mask poses a risk for contamination and a suitable handling guideline is necessary to avoid infections.

4.2. Risk assessment

At high effort intensities, as in an extremely dynamic sport such as ice hockey, respiration risks occur. The following table identifies certain risks related to the use of respiratory masks for ice hockey players. To finalize the product, a detailed risk assessment needs to be performed.

Identified Risks

The following list states first risks identified in the development, offering possible mitigation opportunities:

Air scarcity:

- Supervision of a medical professional & experienced coaches
- Masks being easily removable by athletes
- Implementation of an emergency valve

Carbon dioxide increase:

- Implementation of an emergency valve or active air exchange
- Carbon dioxide sensor

Mask contamination:

- Implementation of hygiene concept around protective equipment and game
- Regularly disinfecting of masks

Loss of mask:

- Reattachment of mask by the player himself (consider limited handling due to gloves)
- Isolation and quarantining if necessary

Material health hazards:

- Only use of materials that are routinely used in medical devices and thus have been tested on humans before

Mask/ filter related contact injuries:

- Full visor helmet
- Soft silicone mask for more safety
- Player already wearing protective gear reduces injury risk when falling

5. Discussion

5.1. Conclusion

This projects study shows that a respiratory mask for sports needs a specific and complex design to fulfil the hockey players requirements and guarantee protection against the virus. Prime restriction is the breathability while wearing a mask. In the developed prototype, the applied filter systems leaning on commercial solutions, did not meet the requirements set by the athletic performance required. Concerning the field of vision, the prototype was more successful. The line of sight can be adapted by improving the geometry of the mask accordingly, still modifications of the used components would impede the use of CE certified parts. An additional valve would allow to solve the drinking problematics and mitigate risks.

A crisis like the COVID-19 pandemic still requires a detailed risk assessment during product development. The importance remains also during a fast-track solution. CE-certified components help to reduce risks and secures a fast development of sustainable solutions, still with the situation relaxing a more detailed assessment is required.

5.2. Outlook

To continue with the development of an ice hockey mask, the filtering system needs to be reconsidered. Possible solutions could rely on:

- one-way filtering of inhalation or exhalation
- increasing the surface of the filter
- adding valves

Another promising option to be considered could be active air support, which offers high protection whilst ensuring normal breathing.

Apart from the application in ice hockey, respiratory masks that ensure normal breathing and comfortable long-term usage is not only relevant for other sports but could provide needed solutions for a wider group of people, e.g. immunocompromised individuals.

5.3. Situation

With government loosening the COVID-19 restriction, professional sport leagues are slowly going back to normal procedures. Protective respiratory masks would still provide a solution to drastically decrease infection risks as training and competition resumes. Obviously, as the situation relaxes and numbers of new infections decreases, athletes will not be asked to wear a respiratory mask and hence the demand is deferred. A resulting perception of a decreased need of urgency increases the burdens in such realization, e.g. testing, certification.

However, a second wave of infections is possible and the absence of a suitable vaccination, could reemphasize the need for design and development of respiratory masks. A long-term project that develops masks suitable to protect athletes and sport players during a second pandemic wave or even future pandemic, could be interesting for professional sport leagues and beyond. Such an equipment could prevent the spreading of the virus among players and reduce the risk of suspend the championship in the future.

Disclaimer

The prototype of a sport mask developed in this project is not a certified or tested protective equipment and should not be recreated as such. The information provided is for general informational purposes only. All information is provided in good faith; however, the authors make no representation or warranty of any kind, express or implied, regarding the accuracy, adequacy, validity, reliability, availability, or completeness of any information published.

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