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Back Protection Concept Design Research

Design a back protection concept for skiing and cycling users

Master of Science Thesis

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Chalmers University of Technology
Department of Product and Production Engineering
Division of Design and human factor
Göteborg, Sweden, May 2012

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The cover picture shows the final design of this study.

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Acknowledgements

I would like to thank my supervisor Thomas Nilsson from Physical Illusion AB and his friend Hans-Arne Jacobsen from G-Spine. They have provided me endless help and cooperation during the master thesis work. Without their help, the thesis will never go smoothly and successfully as it actually does.

Credits and appreciations to my supervisor and examiner, Håkan Almius at Chalmers University of Technology, who constantly gave me guidance and support from beginning to the end of the thesis work.

Big thanks to the support from Human Science Faculty of Design, Kyushu University, Japan, who have provide financial support to the study trip in Japan. Special thanks to Professor Tochihara Yutaka, because he not only share part of my expenditure to Japan but also let me access to all the equipment for the Motion Capture experiment in his laboratory. And also thanks to my experiment supervisor Professor Satoshi Muraki, and a graduate student of Professor Tochihara Yutaka, Xia Yu, who is also a close friend of mine in Japan. They gave me suggestion and assistant during the Motion Caption experiment. Besides, thanks to Professor Hideyuki Takagi, Professor Gerard Remijn who gave me helps in personal life in Japan. Thanks to all teachers and friends who helped me in Japan, they have left me wonderful memory I will never forget.

Thank all of the participants who have attended interviews, questionnaire, observations, both from Sweden and Norway. The data gathered from them is valuable for the research process

Thanks to my Ex-girlfriend and my families for their unselfish support and love during the 2 years study in Chalmers.

Abstract

This thesis is provided by a consulting company, Physical Illusion AB， and based on an idea from a Norwegian company G-spine. The founder intends to develop a new spine protection on sports underwear for athletes when skiing, skating or cycling. It should be comfortable, secure and no movement restriction.

As the initial stage of this project, this Master thesis aims to design a thin, lightweight, and no physical restrain spine protector concept, with focus on visualisation and physical ergonomic aspect, but also consider the material selection, manufacture process, and environment friendly issues in certain depth. The result of this thesis will be presented as several tested wearable prototypes. The result will be used as a concept that will attract further investment and cooperation from other companies.

However, due to some reason, the goal of the thesis was changed twice during the project. As a result, according to the discussion between the supervisor from Physical Illusion AB, supervisor from Chalmers, and the author, the final result will only be a concept evaluation based on current concepts that carried out during the idea generation process.

Content

1 Introduction

1.1 Background

G-spine is a Norwegian company who had the intention to develop a new thin and light back protection product for ski and skate athletes. The owner got the idea because he happened heard complaints from numerous skiers about current back protection on the market are too thick and too warm to wear. Then, Physical Illusion AB, a consultant company, who are also interesting with this idea, took this project and made the first stage of it as this Master Thesis work.

Then, during the ongoing of the process, the goal of the whole project became clearer as time went by. G-spine and Physical illusion AB try to attract more investment and larger market, so they found Helly Hansen A S, who are also looking for some company that can develop a spine protection on their sports underwear product. According to this, the thesis topic has also slightly changed. Before officially cooperation, as a world famous company, Helly Hansen needs to inquire about the capability of G-Spine. This study will give them a first impression on G-Spine and promote further cooperation.

After that, at the final stage of the Master Thesis, there are strategy changes from Helly Hansen. They decide to apply back protection attaching with their ski pants instead of underwear. Therefore, the prototype making is no longer necessary for current stage, because the concepts developed with underwear model are not the perfect continuity for ski pants model. Instead of the prototype make, the final result changed to an evaluation among all the concepts generated within the research, in order to find out the potential solution for future underwear model and ski pants model development.

1.2 Purpose/Aim

The Aim of this thesis is to design a thin, lightweight, and breathable spine protection for athletes when skiing, skating on the sports underwear, in order to avoid high force impact in situations like slip or fall. It should be comfortable, secure but not restricted. The study will focus on physical ergonomic aspect, which refers to the question in this project: “how to eliminate the restriction coursed by the spine protection?” Beyond this question, the visualization, possible material using and manufacturing process could be also included in the study, because they are indispensable parts of the product development process, and the result will be meaningless without consider

of these elements. In order to keep the workload in a reasonable level for only one developer, cooperation and communication between author, company and client is very important.

In the end of the study, an evaluation will be made in order to find a future development track for both underwear model and ski pants model.

During the project, this study engaged in answering the question:
- How to protect spine and eliminate the restriction coursed by the protection simultaneously, when user doing sports?
In order to clarify the research question, sub questions were listed:
-How the back protections protect the spine from injury when athletes fall down?
-What is back movement pattern looks like when individual doing sports or falling down?

1.3 Delimitations

This study was only focused on physical ergonomic aspect, which means it will not go deep into areas like visualization, material selection and manufacture process. The final concept carry out by this thesis will still stay in a concept level, but not a fully detailed mature product.

For simplify the research process, most of physical study, e.g. mockup, motion capture experiment, are established on a male subjects—the author, who is 175cm height, 65kg. If more times are allowed, more subject should be studied to minimize the deviation.

The evaluation process is performed within a small group of interviewees, and the concepts were not fully shown to the interviewees, because those concepts were not patented at that time.

1.4 Overview of the report

The report is structured with 10 chapters. The first chapter contains general introduction of the Master thesis, for example, the purpose and background. Theoretical framework have a briefly introduce about the theory used during the thesis work, which including injury criteria and sports product design principle. They provide basic knowledge and guidelines for further study. Chapter 3 is all about methods used in this thesis work. A short introduction and expiation about the

definition and application of each method is the main purpose to make it as a separate chapter.
Chapter4 development process is an opening chapter for documenting design research process. After that, chapter pre-study, research, design and evaluation phase tells the completely concept design process step by step.
The discussion chapter discuss the questions occurred in method using and general design process, which is meaningful to further study and research. Then, the conclusion chapter make a short summery for the final result and other aspect from thesis work.

2 Theoretical Framework

Theoretical Frameworks contains the theories and principles used in this thesis work. Injury criteria are a basic knowledge when one starts to look into injury and injury prevention area. Moreover, sports product design principle is a general rule to follow when designers focus on user center sports product design.

2.1 Injury Criteria

When doing research about injury and injury prevention, certain criteria need to be used to assess the injury level. Therefore, a currently most widely used scale was applied in this thesis, Abbreviated Injury Scale (AIS), because it has applicability to spinal injuries. It was first developed in 1971 as to define the severity of injuries from motor vehicle crash, and keep updated by the Association for the Advancement of Automotive Medicine (AAAM,1998).

The AIS is a system, which established based on medical diagnosis and developed for injuries caused by vehicular crashes. It is extended in 1990 for more related to medical audit and research. It has six levels, from AIS0 to AIS6, and each level represents a certain danger to life level and the recoverability after treatment. (table 2.1) The higher the AIS level is, the more threating to life it will be. Therefore, AIS0 means no injury, AIS5 is critical injuries, and AIS 6 means currently untreatable injuries.

AIS code	Injury
0	non-injured
1	minor
2	moderate
3	serious
4	severe
5	critical
6	untreatable

Table2.1 The AIS classification

Moreover, the AIS system is not measured with linear scale, because it makes no sense to calculate AIS codes. When describe an overall injury severity for a person with multiple injuries in several different body parts, the Maximum AIS(MAIS) will be used. (Kai-Uwe Schmitt, Peter F. Niederer, Markus H. Muser and Felix Walz, 2010) For example, from a car accident, when a person have AIS3 injuries on his spine, and AIS2 on his head, the MAIS will be MAIS3.

In this Master Thesis, to prevent severe injuries (AIS>2) on spine area by using back protection is the main task need to be done. As a result, to be more specific on spinal injuries, table2.2 shows the examples of AIS code on spinal injuries level.

AIS code	Description
1	skin, muscle: abrasion, contusion (hematoma), minor laceration
2	vertebral artery: minor laceration cervical/thoracic spine: dislocation without fracture thoracic/lumbar spine: disc herniation
3	vertebral artery: major laceration cervical/thoracic spine: multiple nerve root laceration
4	cervical/thoracic spine: spinal cord contusion incomplete
5	cervical/thoracic spine: spinal cord laceration without fracture
6	decapitation cervical spine: spinal cord laceration at C3 or higher with fracture

Table 2.2 Examples of spinal injuries according to AIS scale [AAAM 2005].

2.2 Sports Product Design Principle

To design a back protection product for sports use is a complex research process, which covers ranger of both technical and creative issues. In order to find a break through point from numerous of area for initiating the design research process, an information-tree guideline [Figure1] which emerging from consultation with current sports practitioners (Shishoo, Roshan, 2006) was studied and followed. It is a guideline for general sportswear development research. However, it can be also adapted in sports protection product development, because back protector is a wearable, sports product as well. Because of that, study and understand the "information tree to guide the design research process for performance sportswear designers" is necessary.

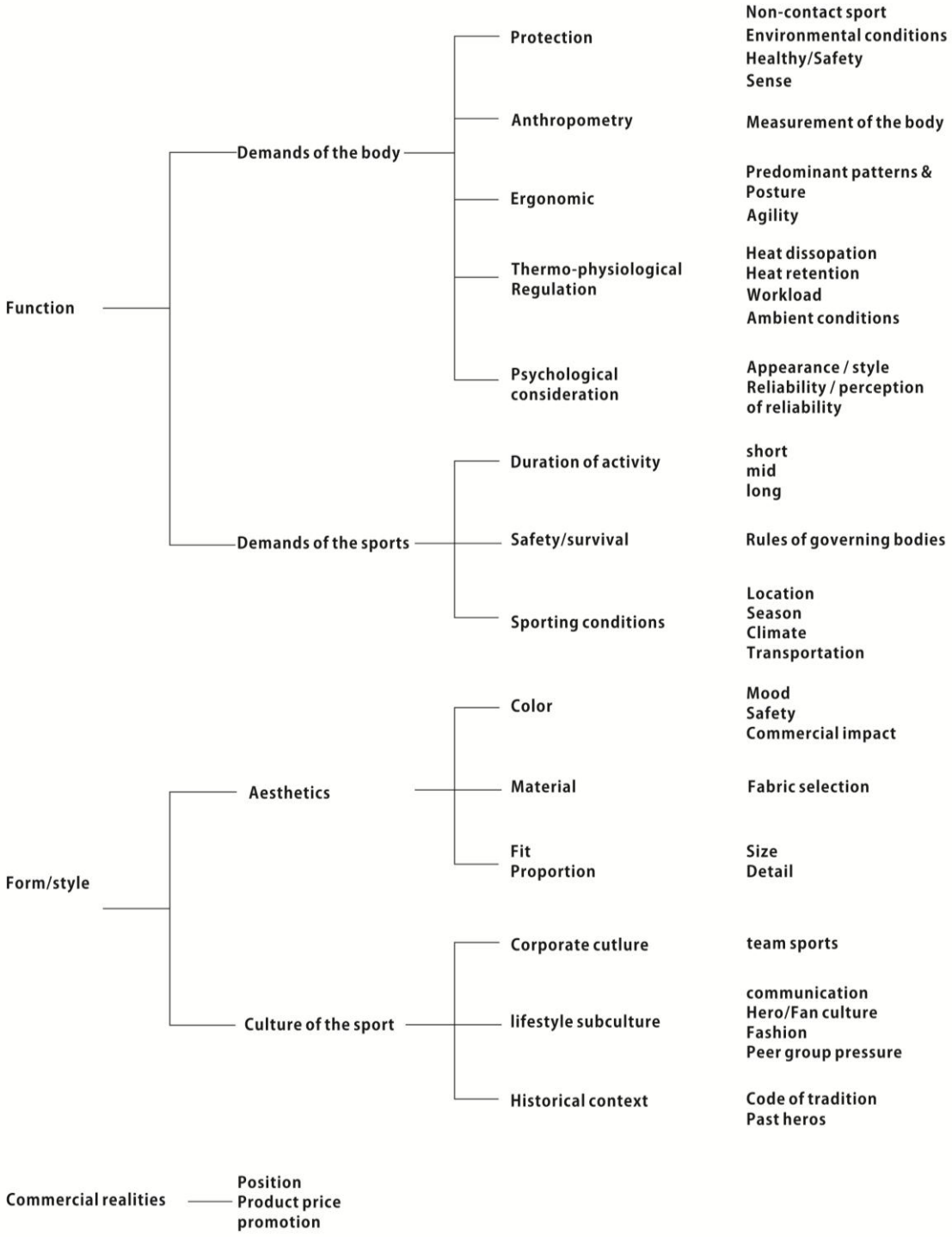


Figure 1 *information tree guide for sports product design(Shishoo, Roshan, 2006)*

2.2.1 Function needs

As can be seen from the guideline, when comes to the function needs from the end user, it always refers to demand of the body and demand of sports aspect. (Shishoo, Roshan, 2006)

The demand of the body comes from five subareas, protection, anthropometry, ergonomics of movement, thermo physiological regulation as well as psychological considerations.

Protection is the subject of this research, as a non-contact sports, the main danger comes from environment to skier or cyclist. Questionnaire aim for clearing the all the injuries caused by environment and climatic elements, for example, temperature, humidity, topography, status of terrain, etc. Another fact that may cause athletes injury is depending on the quality of preparation before doing sports and the health of athletes. For these area, first, the designer needs to understanding the behavior of athletes when they doing preparatory activities. Secondly, finding out the statistic rules between injury locations, gender and ages would provide the designer some useful information for further research. Nevertheless, although ski and cycling are non-confliction sports, but collision by accident is always happened. Thurs, during the interview step, the possibility of accidentally collision also needs to be noticed. Other two aspects, ergonomics of movement, thermo physiological regulation and psychological considerations will affect users comfort feeling. For eliminate sense of restraint of the back protection, the designer need to understand predominate patterns and postures for specific sports. Heat dissipation, heat retention, workload, and ambient conditions are four aspects that need to setup related questions during the interview, if the designer looks into the thermo physiological regulation need of the end user. (Shishoo, Roshan, 2006) The material choice will also dramatically affect the ventilation. Although it is not the focus of the thesis work, but it needs to be always keep in mind throughout the design research process. Psychological considerations, in this case, implies to how the users comprehend reliability from the appearance of back protector without trying it on. Same as material selection, the appearance is also not a main task for this thesis, but “how appearance will affect human purchase behavior” is an interesting topic to study with during the further user interview.

Beside the demand of the human body, the designer needs to study the chosen sport, skiing and cycling, and observing or obtaining feedback from potential user or athletes who uses competitor band product, in order to understand the demands of sports.

The demand of sports also constructed by three subareas, which are duration of activity, safety standard, range of likely sporting conditions. The duration of sports decided the perspiration amount, protector wearing duration and so on. There are certain safety standard for each sports. More information about safety standard of back protection needs to be found in further research. Sports conditions covers questions like, is the sport seasonal, or can they training in different environment? How is the range of temperatures and degrees of humidity changes followed by location and climate changes? How the user carries the protector to the training ground. Is there other gears need to be attached or co-used with the protector? After find out answers to those questions, the design process will became complete and full of details.

2.2.2 Form and style

When comparing with function needs, the appearance of the back protection is not the focus of the thesis work. However, the form and styles somehow affect the ergonomic performance of the back protection. Furthermore, it plays a very important role when the client evaluates the final concept brought out by this thesis work. Because of that, studying form and style need of end user still consider as necessary.

Aesthetics and culture influence of the sport two major parts construct the "form and style need". As can be seen in figure 1, for this thesis work, color, fit proportion from "aesthetics" need, and lifestyle subculture from "culture influence of the sport" need, are more important than others because back protection equipment for skiing is made for personal use, and not always can be seen by other individuals. according to that, the interview afterwards will focus on individual lifestyle and personal taste aspect, for example, inquire about the factors that will affect personal purchase behavior from product appearance, establish personal profile for potential user group and so on.

2.2.3 Conclusion

The information tree guideline provides a clear big picture of sports product design process from the need of the end user perspective. It will also inspire the designer by giving several topics to initiate interview step with potential customers. Beyond that, some detailed information are also included in the guideline, for example, the information conveyed by color, an area consider as secondary but inalienable from the thesis work, and maybe easily ignored without the recommendation from the guideline.

3 Methods

The method applied in this thesis work are briefly described and listed in this chapter, and methods are, interview and questionnaire, Contextual observation**,** motion analysis, biomechanics, image board, mock up and Bionics.

3.1 Interview and Questionnaire

The interview was used to gather information from target group of back protection. Apart from the information from literature study, the designer needs to have a preliminary understanding of the sports, and interview is a straightforward method to get information he needs. Then, the reflections about current back protection products, and expectations about new ones are also useful information for designers. Besides, personal information about target group is important as well, for example, size, injury histories, lifestyles, etc. The questions was brought out according to the "Sports Product Design Guideline" (Shishoo, Roshan, 2006), which mentioned in Chapter2.2, regarding three major areas, inquiry about sports related information, attitude towards the back protection and personal preferences.

The questionnaire was also used in this thesis work. The main reason for using it is that the questionnaire can gather information easy and fast without incurring excessive costs. In this thesis work, questionnaire was specially designed for a group of professional sportsman from Norway, who are an idea target group from the view of the client company. Because of that, except the questions from the previous interview with amateurs, more questions were added from duration of training and injury prevention area.

3.2 Contextual Observation

Observation is a useful tool for gathering information about whole body postures and large scales body movement (Takala, Pehkonen et al. 2010). It is a traditional method when analyzing movement pattern in a dynamic environment.

Besides, multiple methods including interviews, questionnaires and observations, are always used in qualitative scientific studies to reduce the errors. (Sandelowski 2000) By using the 3 methods combination, the subject or interviewee can explain the movement and context when demonstrate them, which helps the interviewer quickly understanding the situation, and coming up with further questions.

Because winter sports and cycling are always present in dynamic environment, the video camera has been used for assisting the observation by naked eyes.

3.3Motion Capture

Motion capture is a method performs by a system owned by Motion Analysis Corporation. (http://www.motionanalysis.com/) The system has a wide variety of applications, for example, virtual training, sports performance, animation and virtual design, etc. (http://www.motionanalysis.com/). The basic principle of the system is, using several special cameras from different angles to trace the reflection sensors that attached on test subject when he or she are requested to perform a certain task, in order to capture the movement of test subject with extreme accuracy. In addition, together with several assistant software, for example, Cortex, EVaRT5, etc., (http://www.motionanalysis.com/) can allow researchers to see capture results at the same time as the subject perform the task, and output the data to Computer Aid Design software for modeling and further researching. Thurs, it is a perfect tool for gathering data from dynamic and complex movement, for example, back movement.
The apparatus used in this master thesis are eagle digital mealtime system and hawk digital real time system, which are bought by Professor Tochihara Yutaka, from Human Science Faculty of Design, Kyushu University, Japan. (http://www.kyushu-u.ac.jp/english/index.php)
The whole experiment is hold in his laboratory (http://www.design.kyushu-u.ac.jp/id/ninkou/tochihara/English1/framepage.html) with assistant from one of his graduate student, and guided by Professor Satoshi Muraki (http://www.design.kyushu-u.ac.jp/~muraki/eindex.html),
The reason why motion analysis system are used in this master thesis is because it has unique compatibility to this project, and the output data has driven the design process as well.

3.4Biomechanics

Biomechanics is a principle used to investigate the mechanical construction and dynamics within body of creatures. It has wide range of application and subfield. (Masahiro Nishida, 2009) In this Master thesis work, biomechanics are applied in calculate the impact or average peak force when people fall down from certain height, which is a typical subarea of biomechanics, impact biomechanics. It refers to studies of prediction of bone fracture and soft tissue damage (Masahiro Nishida, 2009) by calculating the speed, falling height, etc.

3.5 Image Board

Image board is a traditional method used by designers, when they need to be inspired in visual form design. It usually contains visual materials like pictures representing similar scope of styles, colors, feelings or atmosphere, etc. For this master thesis work, image board was used in concept development process, together with sketches, and paper mockup, in order to find best structure for the back protection.

3.6 Mockup

In general, a mockup is a scaled or simplified model of a structure or device, which usually used for ergonomic assessment in design process. It does not have a full function of the concept, but a reflection of its structure and ergonomic features. It widely used in ergonomic related product development process, for example, tools design, user interface design and artwork design, etc. For this master thesis, after the concept was generated, mockups need to be made and tested from size, coverage and comfort aspects by using low cost material. It can lower the cost by avoiding having gone back and make expensive changes after make the final prototypes. The mockup making process is along with concept development, which means modification are made after the test, then new concept will continues the loop. In addition, despite the traditional application of the mockup methods, another paper mockup method was also used in this thesis work for searching appropriate structure for the back protection. By using paper mockup, the designer can arrange the structure by hands instead of imagination, which is more intuitive and efficient.

3.7 Bionics

Bionics or Biomimetic is a relatively young study including mimic the nature biological mechanisms and processes in engineering, design, chemistry, electronics, and so on (Julian F. V. Vincent, Olga A. Bogatyreva, Nikolaj R. Bogatyrev, Adrian Bowyer and Anja-Karina Pahl,2006). However, in 3000 years ago, the ancients already started to get inspiration from nature. Nowadays, designer and engineer become more focus on details and systematically draw inspiration from nature, and create a new path to find the solutions. Because of that, there are more and more successful examples coming out in energy, material, medical, and product design aspect.

Human spine is an art of nature. It is flexible but supportive, and it unique mechanism cannot be replaced by normal artificial structures. As a result, if a spine protection

needs to be found, the best way is to find it in nature. That is why bionics was used in this project.

Bionics, as an inspiration tool, was used together with image board and paper mockup, because a simple and direct duplication of a biological structure is rarely successful (Julian F. V. Vincent, Olga A. Bogatyreva, Nikolaj R. Bogatyrev, Adrian Bowyer and Anja-Karina Pahl,2006). Changes need to be made according to actual situation, meanwhile core biological principle needs to be kept.

4 Development Process

The concept development was gone through four phases: pre-study phase, research phase, design phase and evaluation phase. As can be seen in Figure2, at pre-study phase, the knowledge regarding human spine anatomy, distribution of human sweat gland, sports related injuries on spine area, safety standard, and sports product design guideline was studied through academic literature study. The research phase was aimed to understand the market, clarify the movement pattern of human upper body when skiing and cycling, and setup persona. Design phase was divided into four stages in this thesis: idea generation, concept development ,visualization and mock up. At the ideation stage, authors generated ideas based on the information gained from pervious phases, for example, interview and motion analysis. Then, the initial concept was transferred to the further concept development stage after filter. At concept development stage, the chosen concept was further developed into three or four feasible concept, with consideration of material selection and manufacture methods. At visualization stage, the four concepts narrowed down to 1 or 2 final concept for further test and prototype. At the same time, more details added on geometry, joining, etc. At the evaluation phase, material and structure were tested instead of making prototype, due to the purpose changes from the client. In the end, an evaluation was made to assess the potential of each concept that developed during the thesis work.

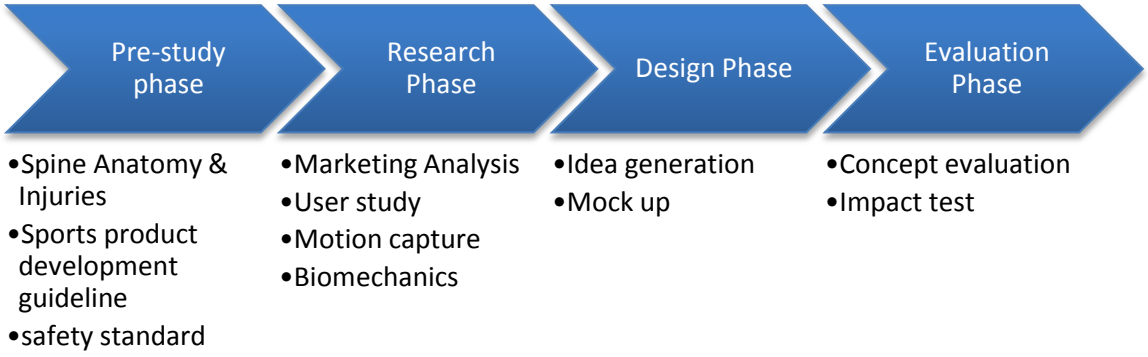


Figure 2 developement process

5 Pre-study Phase

At pre-study phase, several topics that related to winter sports back protection design were explored through academic literature. Therefore, spine anatomy, spine injuries and human gland distribution consider as tree basic knowledge that need to be understand before research and design process.

5.1 Spine anatomy

Spine or backbone, in human anatomy, is called “the vertebral column” (Latin − *Columna vertebralis*), which is a column usually consisting of 24 articulating vertebrae[1]. If assuming coccygeal as four separate vertebrae, the vertebral column is consist of 33 vertebrae, according different references [Figure 3]. Each individual vertebra is constructed by a cylindrically shaped body, a vertebral (or neural) arch, the (dorsal) spinous process and transverse processes at each side (Schmitt, Kai-Uwe and dawsonera,2010) [Figure 4]. The major part is a cylindrically shaped body, which support the body weight. The Spinous process and two Transverse facets on each side form a reversed “W” shape. The W-shape and vertebral body format a hole between the skeleton, where the spinal cord through this tunnel.

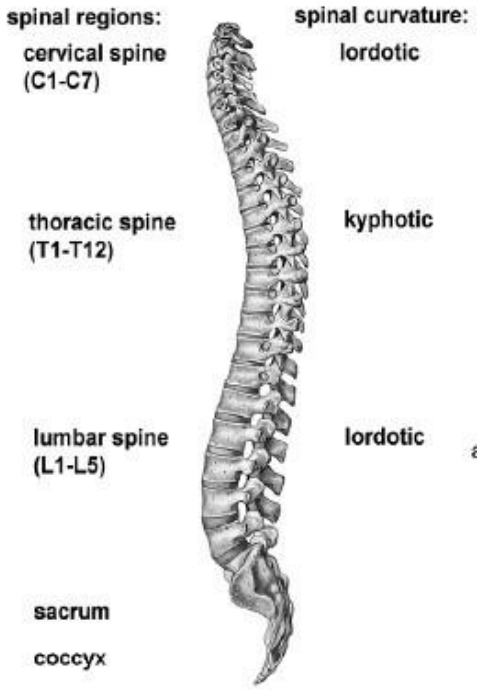


Figure 3 Human spine (adapted from Sobotta 1997).

[1] "vertebral column" at *Dorland's Medical Dictionary*

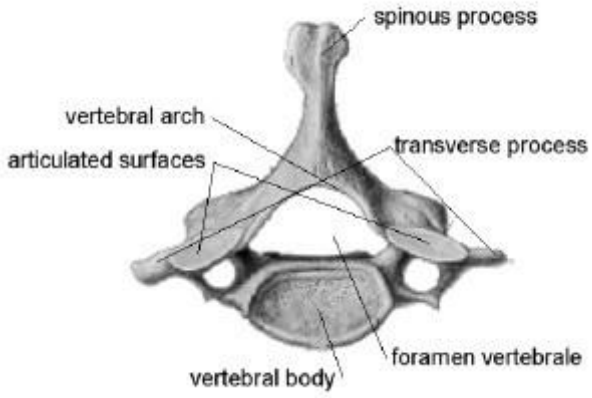


Figure 4 Different regions of a vertebral body (adapted from Sobotta 1997).

From superior to inferior, the individual vertebrae are named according to region and position [Figure 3], which are listed below:

- Cervical: 7 vertebrae (C1–C7), neck
- Thoracic: 12 vertebrae (T1–T12), up back
- Lumbar: 5 vertebrae (L1–L5), low back
- Sacral: 5 (fused) vertebrae (S1–S5)
- Coccygeal: 4 (3–5) (fused) vertebrae (Tailbone)

Cervical spine is from vertebrae C1 to C7 , thoracic vertebrae is from T1 to T12, and lumbar vertebrae is L1 to L5. The sacrum and the coccyx as a part of the pelvic girdle, support the entire column (Schmitt, Kai-Uwe and dawsonera, 2010) .

Besides, from cranial to caudal, the sizes of the vertebrae are gradually increased. the width of vertebral body is averaged 47.6±5mm(Cameron R. 'Dale' Bass, Karin A. Rafaels , Robert S. Salzar, Marina Carboni, Richard W. Kent, Michael D. Lloyd, Scott Lucas, Kevin Meyerhoff , Chris Planchak , Andrew Damon, Gregory T,2007).

The average length of whole vertebral column in the male is approximately 71cm, which contributed by cervical, 12.5cm, thoracic 28 cm, lumbar 18 cm, and sacrum and coccyx 12.5 cm. (Photius Coutsoukis, 2007).

For this Thesis work, the research will focus on area from vertebrae T1 to S5, where sports underwear tops are normally covered.

5.1.1Function

The four main function of the spine:

- Support the body weight.
- Conduct sense of gravity, in order to maintain body balance.
- Protect spinal cord and nerve root, in order to receive and deliver information.
- Protect internal organs together with ribs and pelvis.

According to the structure of spine, there are four basic movements upper body allow make, which are flexion, extension, lateral bending and (axial) rotation.

5.1.2 Curves

From the front view, the normal healthy spine is straight. From the lateral view, the entire spine appears three principal spine curves: the lordotic cervical (Convex anteriorly and concave posteriorly), lumbar curves and the kyphotic thoracic curve (Concave anteriorly and convex posteriorly) [Figure 3].

The normal curvature of thoracic kyphosis is 20 to 40 degrees, and lumbar lordosis is 40 to 60 degrees. Another fact needs to be notice is the lumbar curve in a female is more marked than in the male. (Photius Coutsoukis,2007)

Due to the time limits, the further analysis will only base on male who wears S to M size, but the final result should be adjustable and scalable for full size needs, including female size.

5.1.3 Superficial Layer Muscles

The superficial layer of the posterior muscles of spine is also need to be studied, Because the back protection will contact with muscles surrounding the spine area, and the contraction and extension of each muscle will affect the feeling of constraint and comfort of the protection wearing.

There are four main muscles around the spine in superficial layer, which are Ligamenum nuchae, Trapezius, Latissimus dorsi and Thoracolumbar fascia. [Figure 5](Vleeming A, 1995)

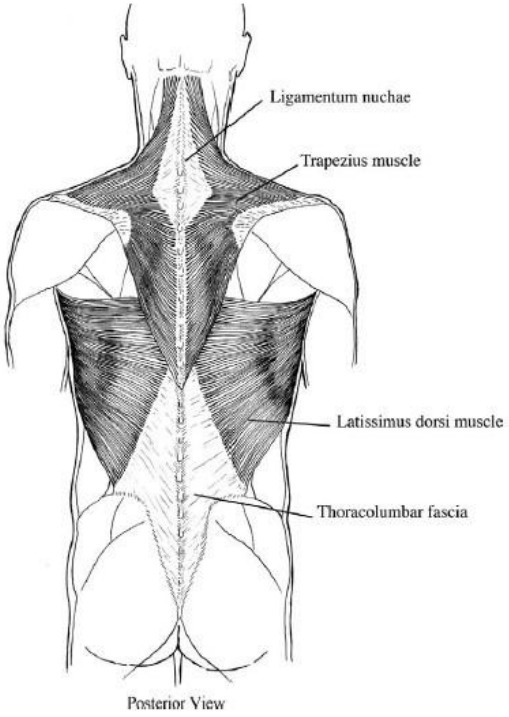


Figure 5 the superficial layer of the posterior muscles of spine (Vleeming A, 1995)

In general, Ligamenum nuchae is involved in cervical movement, so it is not included in the research area of this project. Trapezius can be divides into upper, middle and lower fibers according to their locations. The upper fibers are activated when scapula elevation, and cervical extension. The middle fibers are involved in scapula adduction, elevation, and upward rotation. The lower fibers not only control upper rotation, adduction and depression of the scapula, but also have weak impact on thoracic and lumbar extension. The latissimus dorsi plays an important role in extension, adduction, transverse extension of the shoulder joint as well as extension and lateral flexion of lumbar. (Photius Coutsoukis, 2007) The thoracolumbar fascia is responsible for the trunk extension and rotation. (Nabil A. Ebraheim, MD, Ali Hassan, MD, Ming Lee, MS, and Rongming Xu, 2004)

The movement of each posterior muscles is delicate and complex, to have brief understand of their function and arrangement will provide a big picture to the designer, when he or she start protection module arrangement.

5.2 Human Sweat Gland Distribution

To design a back protector with good ventilation and avoid overheating is one of the requirements from the client. In order to achieve this goal, human sweat gland distribution needs to be study, because it decides perspiration area and the sense of temperature when people wearing the protection.

The data used in this report is come from an experiment brought by George Havenith, Alison Fogarty, Rebecca Bartlett, Caroline J. Smith and Vincent Ventenat in 2007. They measured 9 male and female upper body sweat distribution by collecting their sweat production with sweat absorbing materials after running. The result is showed in figure 6.

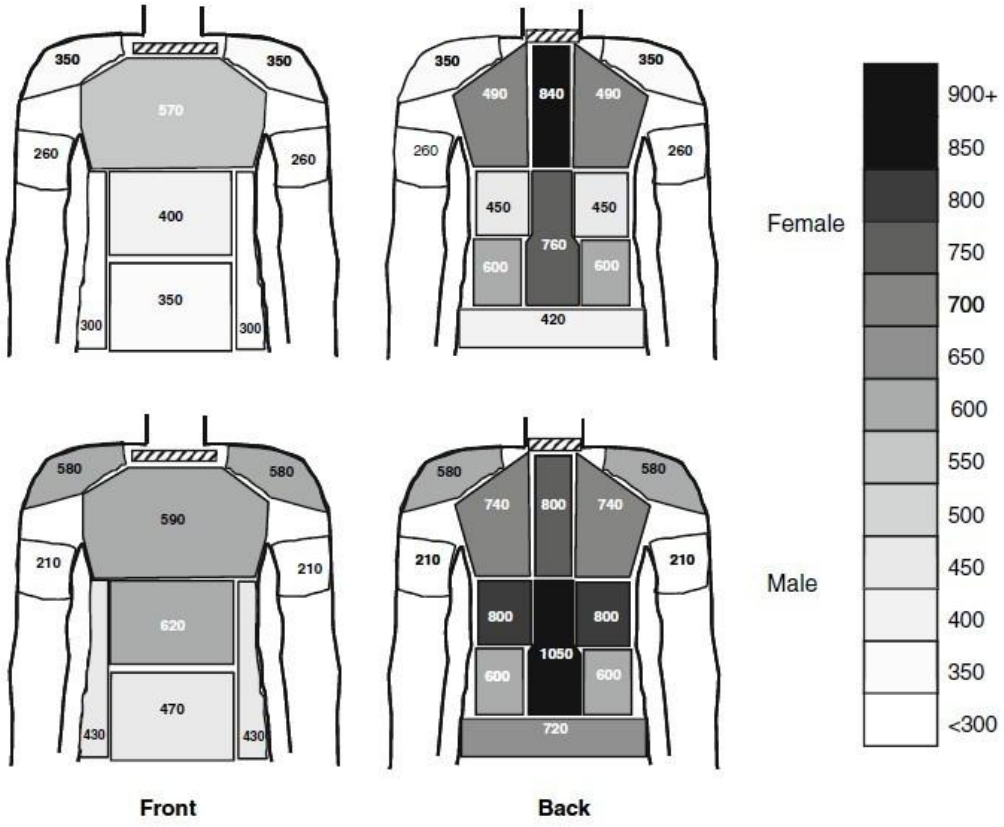


Figure 6 Median regional sweat rate values for male and female runners, rounded to nearest 10 g and averaged over left and right symmetrical zones

As can be seen from the picture, in general, with equal relative workloads, male have higher sweat rate than female, and the spine area have highest regional sweat rate than others in both female and male subjects. To be more specific, the mid central and mid low back area took the first place of male the highest regional sweat rate area, left and right central back as well as top central back area took the second place together. Then, scapula area followed behind. On the other hand, for females, the top central reach the highest regional sweat rate, then, the mid central and low central followed behind. To summarize, the male and female, have relatively same sweat gland distribution, the slightly differences on top central part is explained as caused by sports bra wearing from female test group.

When it comes to the back protection design, as described above, the high sweat region on human back is the right area need to be protected, which means the

protection have to cover those area. Because of that, the ventilation solutions needs to be further explored instead of simply leaving the open area.

5.3 European Standard

At presents, British standard EN1621-2 (BSI Group, 2003) have been established for back protection for motorcyclist. Simultaneously, this standard is also applied to access to other sports protective clothes, (e.g. back protection for ski and snowboard) and there is no other specific standard for spine protectors for other sports. Except declare some basic criterion like, the minimum dimensions of zones of protection, labeling and the provision of information, British standard EN1621-2 also describe a general procedure to an ergonomic test and an impact test for every back protections with some recommended apparatus. Despite other basic information, the ergonomic test and impact test mentioned by EN1621-2 consider as the most important two tasks within this Master Thesis, so it will be further discussed as follow.

5.3.1 Ergonomic Test

The ergonomic test mentioned by EN1621-2 is relatively simple, the test including (BSI Group, 2003):

1) can you get on and off a Motorcycle;
2) can you comfortably reach the controls of the Motorcycle;
3) can you turn your head and torso when on a Motorcycle;
4) does the adjustment system cause discomfort;
5) does the adjustment system securely hold the protector in place;
6) can you pick something up from the floor by bending forward.

As can be seen from the list, the ergonomic test only including the basic non restrain requirements when riding a motorcycle, And it also lack of supplement for winter sports back protection test. However, some of movement that mentioned in the clause can still be transferred to winter sports movement, for example, turning head and torso, bending forward. The adjustment system check can also apply to winter sports protection usage. Although the test methods seems transferable from motorcycle to ski or snowboard back protection, but there are enormously differences between motorcycle and winter sports from body movement of the athletes, sports equipment using, and sports environment aspects. Even so, as the British standard EN1621-2 is the only and compulsory standard that every back protection should be fulfilled, further research should be done to find out a solution that not only fulfill the requirement from skiing or snowboarding, but also above or equal with the British standard EN1621-2.

5.3.2 Impact Test

Except from ergonomic test, EN1621-2 has also prescribed an impact test method for inspecting back protectors. The basic idea is drop an anvil with weight of 5 kg from 100cm height to the test back protection, in order to generate a 50J kinetic energy as impact. The result is recorded from the load sensor beneath the back protection. The average peak force is used to judge the protection whether pass the test or which level it is reached. For level 1 protectors, the average peak force shall below 18kN and no single value shall exceed 24kN. On the other hand, for Level 2 protectors, the average peak force shall below 9kN and no single value shall exceed 12kN. (BSI Group, 2003)

However, as can be seen from the description of the impact test, it is not built on a clear biomechanical basis. (Cameron R, etc., 2007)First of all, 50J input energy is not based on any biomechanical calculation. For example, assume a person with torso mass of approximately 30kg, and when he falls from 1m height, the impact energy to the spine is about 300J, which is far more than 50J. Correspondingly, the criterion for the test result is also difficult to understand as well. A threshold of shear force, which will not cause injuries to human spine, is about 845N to 2kN, according to the experiments made by Mertz & Patrick, 1971, and Goldsmith & Ommaya,1984.(Kai-Uwe Schmitt, Peter F. Niederer, Markus H. Muser and Felix Walz,2010) Thurs, 24kN is not close to this numbers, and lack of explanation as its input energy does.

To sum up, this impact test method mentioned by CE standard may not perfectly fit for winter sports protection equipment use. However, based on the fact that every back protection need to pass this test, it will be used as a tool to exam the final product, but not as a reference for design process.

5.4 Ski and Cycling Related Spinal Injury

There are two types of sports related spinal lesions, overuse and acute injuries. Obviously, only acute spinal injuries will be discussed in this Master thesis. In sports related acute spinal injury, the compression fractures of vertebral endplates, which always happened in ski, snowboard and equestrian, and caused by sudden axial load impact, are the most common ones. Compression fractures are consider as the second of most common injuries in sports which requires high jump or axial load spine stresses, e.g. snowboard, gymnastics, etc. (Tall RL, DeVault W, 1993)

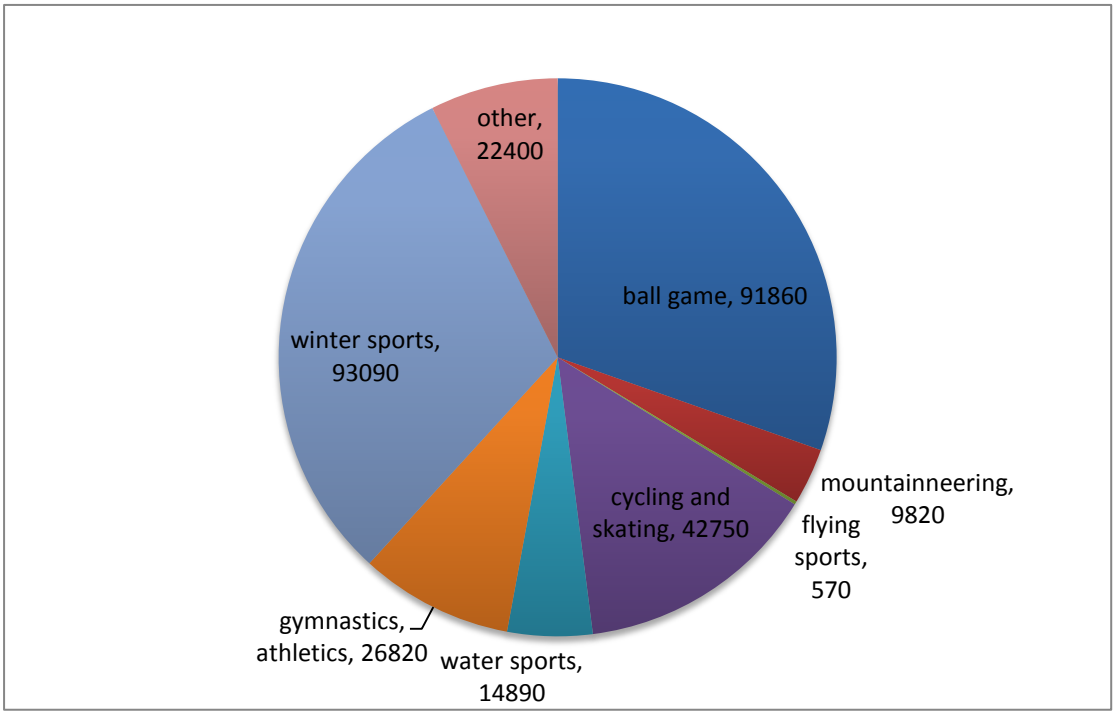
5.4.1Injury rate and localization

According to a research named "a 10-year review of sports-related spinal injuries" made by S. Boran, 2011, point out that among the 196 sports related spine injures happened in Ireland from 1993 to 2003, the most common sport may causes a spinal injury was equestrian(41.8%), after that is rugby (16.3%), diving (15.3%), Gaelic football and hurling (9.6%). Surprisingly, cycling and skiing only response for 4.2% and 1.2% respectively from all the specimens. Correspondingly, the main injury mechanism is falling from ski jump and from the bicycle. For skiing, excess speed, loss of control led unexpected landing directly onto the lower back or buttock of the skiers have been found to be the main reason for causing the spinal injuries(Prall JA, Winston KR, Brennan R, 1995). This kind of sudden axial loading will cause acute fractures are compression fractures on vertebral endplates, especially on thoracolumbar junction and lumbar area, because the thoracic segment is more rigid than the lumbar spine (Hainline B,1995). For cycling, it shares the similar injury mechanism with skiing, but the injury pattern is slightly different, which are 75% on cervical, 25% on thoracic, and 12.5% on lumbar (S. Boran, 2011). Another fact that needs to be noticed is that, the treatment of spinal injuries is complex or not found yet, and some of the trauma cannot be 100% recovery. Depending on the locations of which the spinal cord and nerve roots are damaged, the related symptoms can vary widely, for example, like pain, paralysis or incontinence. (Kirshblum S; Campagnolo D; Delisa J, 2001)

Another statistics made in Switzerland in 2010(bfu – Swiss Council for Accident Prevention. STATUS 2010)shows the similar result as the S. Boran did. The statistic is based on around 300 000 sports groups per year, from 2000 to 2008, with focus on snow sports, which is informative to this Master thesis work.

According to the statistic, from 2004 to 2008, the number of injured people caused by winter sports is about 93 090. It almost equal as the number from ball game, 91 860, and share the one third of the total number of injured people including from ball game, winter sports, mountaineering, flying sports, cycling and skating gymnastics, athletics water sports, and other types of sports and games. [Table 5.1]

Table 5.1 *Persons injured, by type of sport, 2004–2008 (bfu – Swiss Council for Accident Prevention. STATUS 2010)*



When comes to spinal injury, for male, there are 5 person per hundred will be suffer during downhill skiing, 8 of hundred person will be injured when snowboarding, and 5 person per hundred from cycling. Simultaneously, for female, 15 per hundred will be injured from snowboarding, 8 will be in downhill skiing, and 2 from cycling.which is a relatively small figure when compare with other body parts injuries. [Table5.2]

Table 5. 2 *Injury localization by gender, in selected types of sport (per 100 persons injured), 2004–2008(bfu – Swiss Council for Accident Prevention. STATUS 2010)*

	Male	Female
Snowboarding	8	15
Downhill skiing	5	8
Cycling	5	2

There are also some other research pointed out that approximately 23% of all sports injuries in Switzerland occur during alpine skiing and snowboarding. The most frequent injury location during alpine skiing affects the knee (34%) and for snowboarding the region around the shoulder and the upper arm (Niemann S, Fahrni S, Hayoz R, Brügger O, Cavegn M.2009). The amount of injuries of the spinal column

varies between 2-10% (Ackery A, Hagel BE, Provvidenza C, Tator CH, 2007). They also prove that spinal injuries happened in winter sports are quite rare.
Another contribution the statistic made is the investigation of personal protective equipment using in winter sports.

From 2004 to 2008, almost every person wearing goggles during skiing and snowboarding. In the contrary, the protective jacket usage is taken much lower percentage compare with the usage of goggles or other equipment. For snowboarding, the number of people who wearing back protection or protective jacket was gradually growing each year, from 21% to 49%. When compare to skiing, not only the usage of the back protection and protective cloth were not widely as in snowboarding, but also the increasing rate was much lower, which is only from 3% to 13%.[table 5.3]

Table 5.3 *Protective behavior in percent, in snow sports, 2004-2010 (bfu – Swiss Council for Accident Prevention. STATUS 2010)*

	2004/05	2006/07	2007/08	2008/09	2009/10
Ski					
Goggles	95	96	96	97	97
Back protection/protective jacket	3	7	6	13	13
Snowboard					
Goggles	93	90	90	98	99
Back protection/protective jacket	21	38	41	38	49
Wrist protection	40	42	49	36	27

In a conclusion, spinal injury rate in the winter sports is relatively lower than in other sports, like rugby and equestrian. Within the winter sports related injure, spinal injure still keep a lower rate than other body parts, like, wrist and knees. However, due to the severe consequence spinal injuries may lead to, person back protection is strongly suggested, and the awareness of wearing protective cloth became prevalent within winter sports population year by year. The reason why individual consider goggle and other equipment are more important than back protection will be further investigated during interview in next step.

5.4.2Injury Threshold

In order to design a back protection, a suitable injury protection standard and protective design requirement need to be found. Since British standard EN1621-2 (BSI Group, 2003) fail to provide a feasibility protective standard for design winter sports back protection, some other studies already been made to find out the injury threshold of thoracic and lumbar spine injuries. For lumbar spine, compression fractures were happened between loads from 2kN to 6 kN, due to different experiments (Hutton and Adams 1982, Myklebust et al. 1983, Yoganandan et al. 1988, Myers et al. 1994, Belwadi and Yang 2008).

There is also an experiment carried out by Cameron R et al., 2007. They using cadaveric porcine specimens instead of human to determinate an appropriate injury threshold value for thoracic and lumbar spine injuries. Because of that, the result is much more specific than other research: *"The injuries ranged from mild spinous process fractures to endplate fractures with anterior longitudinal ligament (ALL) transactions with a maximum AIS = 3. The average peak reaction force for the thoracic failure tests was 4720±1340 N, and the average peak reaction force for the lumbar failure tests was 4650±1590 N."* (Cameron R et al., 2007)

As mentioned before, thoracic and lumbar spinal injuries usually caused by direct spinal impacts (Gupta et al., 1982). So that, after knowing the threshold, with the helping of biomechanics, a standard for human injury risk or a guide for designing safety equipment for the back can be ensured in further research process.

5.5 Summery

Through the research phase, several facts need to be noticed during the further research and development.

For a back protection built on underwear, vertebrae T1 to S5 should be covered. The average width of vertebral body is 47.6±5mm, and the length of whole vertebral column in the male is 71cm. It means the minim size of the back protection should be larger than these numbers.

Human spine supports the body weight and allows four basic upper body movements, which are flexion, extension, lateral bending and (axial) rotation. The back protection should not cause restrain feelings to these four basic movements.

From lateral view, the entire spine appears a double "s" curve, and lumbar curve in female is more marked in male. It is an important fact when design a unisex back protection.

The superficial layer muscles study provides a big picture of the relationship between muscles extension/contraction and skeletons' movement. However, the information is useful but limited. Back movement pattern study needs to be carried out with other advanced experiments or methods.

There are studies demonstrate that the spine area in human back happened to be the high sweat region during the sports, when compare to other area on the back.

Therefore, the ventilation solutions cannot be addressed by simply leave the opening gaps.

The CE standard is a standard every back protection should pass, which cause problem in the beginning of the thesis work. The first goal of this thesis is to design a thinner back protection for cross-country skiers who do sports with lower speed, and no high jump movement. Reducing the thickness will lead the new back protection fail to pass the CE standard.

The CE standard also describes basic experiment to exam the ergonomic aspect and impact resistance. For ergonomic aspect, the experiment is only available for motorcycle back protection. For Impact test, it only provides a method to record the force transmit through the test back protection, but do not have a clear biomechanical basis. In this case, CE standard EN1621-2 will only be used as an exam tools at the end of the thesis.

According to statistic, back injuries are rare but fatal in winter sports or cycling. Using back protection can dramatically lower the injury rate, and that it why back protection using rate is rising in recent 5 years.

Another important fact about spine injury is about threshold. The average peak reaction force that cause thoracic failure is 4720 ± 1340 N, and the average peak reaction force cause lumbar failure is 4650 ± 1590 N. Because of that, back protection should lower down the impact to this level to avoid spine injuries. Biomechanics calculation needs to be further studied within context, to ensure the force resistance level of the back protection.

6 Research Phase

The research phase begin with market research, for letting the designer have a general impression of existing back protection products. Then, the potential user interview was hold after preparation from both pre study phase and market research. In the final stage of research phase, motion capture experiment was carried out for collecting data complementing details.

6.1 Market Analysis

Market analysis is performed within Gothenburg, Sweden. Several winter sports store have been visited. Information gated both from technical manuals of the products and the introduction from the storeowners. Then, comparison was made among 10 different types of products from aspects like, safety, material using, technology using, coverage, wearing method, price, personalization, etc. the result was shown in figure 7

Brand	FOX	SCOTT	POC	POC	KOMPERDELL	Sweet Protection	Pro-TEC	SixSixOne	DAINESE	ATOMIC
Internal Material		Darlington mesh fabric				Cool MAX®	DRI-Lex® Hydrophobic fabric Hydrophilic fabric		EVA foam	Polysterol (EPS) Polystyrene
External Shell material	Polyester Polypropylene Ethylene vinyl acetate Polyamide	Polyester Polypropylene Polyamide d3o®	Visco-Elastic Polymer Dough (VPD)	Polyester Polypropylene Polyamide						
Thermo-shape	✓		✓		✓					✓
For ski	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
For mountain bike	✓	✗	✓		✓		✓	✓	✓	
Shoulder protection	Removable	✓	Compatible	✗	✗	✗	Removable	✓	✗	✗
Coccyx protection	Removable	✓	✓	✓	✓	✓	✓	Removable		
Neck protection	Compatible	Compatible								
Fix method	Zipped vest Wrist band	Shoulder belt Zipped vest Double elastic wrist belt	Zipped vest Wrist band	Shoulder belt Wrist belt	Zipped vest Wrist band	Shoulder belt Wrist belt	Zipped vest Wrist band	Zipped vest Wrist band	Shoulder belt Wrist belt	Zipped vest Wrist band
Standard En1621-2	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Weight	1100g	900g	1000g/1300g	700g	500g	700g	1700g	1100g	800g	600g
Price	■■■■	■■■□	■■■□/■■■■	■■	■■■■□	■■	■■■■□	■■■	■■■	■■■□
Color scheme/size for female	✓									
Removable &washable lining	✓	✗	✓	✗	✓	✗	✓	✗	✗	✓

Figure 7 result of market analysis

6.1.1 Safety

As can be seen from figure7, from the Safety aspect, the chosen back protector in the market are all be certified by CE EN 1621-2. As it mentioned before, there is no specific standard for back protector design for winter sports, which means CE EN 1621-2 is the only standard that all the protective cloth sells in Europe should be fulfilled, which also mean if they are certificated by this standard, all those products could be used in both winter sports and motorcycle sports. However, one should not use a back protector isolated from chest, shoulder, elbow and other parts of protector when he or she doing motorcycle sports. According to the market research, most of the brands have another protective cloth specifically made for motorcyclist, which constituted with chest, shoulder, elbow protector and the same back protector as the one used in winter sports, but only SCOTT made a clear and obvious warning "only for winter sports" on its winter sports back protectors

6.1.2 Material usage

The material used for out shell is a most important part of the research, although the information can be collected is considerably limited. The out shell of the back protectors are normally made of plastic like, polyester, polypropylene and polyamide, which we can call it "stiff" material when compare with d3o^{TM}, (D3O lab, 2010)VPD or some special foams. The latter is more flexible and elastic, which will reduce the restriction to the body movement when adopt it into the back protector. For example, the VPD board can slightly be bended horizontally but can hardly be squeezed vertically, which make it as a perfect material for back protection. Moreover, some of the "soft protectors" are thermo-shaped, which means they are changing the shapes along with the body temperature rising when people doing sports. It no doubt fit every individual's back even better than those "stiff" out shall protectors. It also explained why they are sells way better than the stiff ones, even the price much higher.

From the market research, using soft and flexible materials instead of stiff ones seems became a trend in out shell design.

However, the traditional "stiff" back protector is still dominating the market by its cost-efficiency. So the relationship between the price and the ill-fitting caused by back protector shall be further invested.

In spite of the out shell, the breathable lining is also a key element of the back protector. Alike the out shell material, it is also very difficult to figure out the particular materials they used in lining or internal parts. From the label of introduction,

it can be seen that some of the material weave nylon and lycra together, but most of the manufactures just give some commercial names in order to protect their patented material components, for example, DRI-lex@, Cool Max@, etc. However, no matter what material they used, it should be breathable and comfortable to wear. Through the observation, most of lining made up by using honeycomb shape holes in order to add ventilation, and some of the internal parts also have the function like absorb the impact from external shell. In addition, there are also some complain about the honeycomb hole structured lining is easy to break from the customer who have the product.

6.1.2 Compatibility

Compatibility with neck, shoulder and coccyx protection is also one part of the research. As mentioned above, different from back protection for winter sports, mountain biking and motorcycling needs chest, shoulder and neck protection also. Most brand make two different type of product for each sport. However I also found some of the brands make some parts removable according to consumers' personal preferences. For example, Fox, all the parts can be removable, the shoulder, the coccyx, and the back protector. Each of them can become an isolated part, which offers more choice when one does different sports in different times. Moreover, FOX also design its own professional neck protector which only compatible with its body armor, which can be consider as a positive marketing strategy.

It also can be found that, those out shell made by soft material normally do not have "removable parts" feature, although the reason should be further investigated. The manufacture method and cost would be one of the reasons.

6.1.3 Wearing and Fastening

Although the way to put on and fasten the protection will not be a part of the thesis work, but to understand traditional or prevalent fastening method may have positive affect on design and evaluation phases.

From the way wearing the protector aspect, most of the brands using a zipped vest added with a wristband to be fixed on human's body. It is easy to understand that using the zipped vest will be an easiest way to set the multiple protection parts be the right place they should be. Wristband not only helps adjust and room between wrist and the spine protection but also fix the protector from slip horizontally. There are also other fix method been used in back protector, for example shoulder belt cooperated with wrist belt , and from SCOTT, even with triple indemnity which is a

combination of Shoulder straps, thoracic belt, hip belt and half-vest zip closure. It can be seen from the details on “SCOTT” products that they put huge efforts on ergonomic and safety aspects when design fit in and connecting methods.

6.1.4 Commercial issue

From the commercial perspective, among all the back protectors, those who apply innovative material into the product usually have the higher price. Protector for motorcyclists or bicycle riders is more expensive than winter sports product within the same brand. In the selected interview group, Scott is the only brand that offers the protection special designed for female. If only count the back protection, the weight of the protectors is close to each other, between 500g to 1000g. The POC named the heaviest, meanwhile the Komperdell which using a special form material as out shell is the lightest. In addition, there are several brands offer removable and washable lining, which would be an advantage when the back protector became dirty.

6.1.5 Conclusion

Every brand that was investigated in this research all has a clear target group. According to their target group, they promote their products in different ways, for example on function, price, quality, size, graphic design, and material selection. However, there are also some similarities among them, which is they all applied innovative technology in their product. It also implies the trend of the protective cloth development, which is to become thinner, lighter, as well as more comfort and secure.

6.2 Potential User Interview

9 interviewees, age between 24 to 30, one female included.7 of them are amateur sports men who usually spend one or two weeks per year on ski or skate. The other two of interviewees are former professional sports man, they used to training for skiing or cycling whenever they have time during their career. Besides face to face interview, questionnaire also been used among 3 former sportsmen and 6 professional cross country ski athletes (5 male, 4 female) in Norway, which also consider as our target group of our product. The questionnaire is based on previous interview, which means it is a survey that contains questions more in depth and professional.

6.2.1 Interview

There are three purposes of face to face interview. First of all, in order to start design a product for certain sports, one needs to have a preliminary understanding of the sports, for example, cross country ski, land ski, etc. After that, the relationship between the sports and the user needs to be clarified. Thirdly, it is important to know their feelings and expectations on the back protection they are using or intend to use.

In order to achieve the goal, the interview contained questions about "which extreme sports they usually participate in?", and "how is the environment when they exercise?", as well as getting broader information about the participators (sex, age, weight, time of using protection , etc.), that are the most common. Questions, for instants, "which movements would use back rotation" will be asked as to understand the back movement pattern when subjects doing sports. Scale system is introduced to evaluate their feeling of the back protector they are using now. Back injuries that caused by trauma are topics of interest, and could further followed during the whole research phases. There are also some open questions related to suggestion and expectations about back protector design, which would help when comes to design phase.

6.2.2 Questionnaire

The aim of this study is to understand the difference between professional sports man and amateurs from performance, injury locations and preference on protection products.

The questionnaire covered the same issues as the interview questions (regarding their practice of the sport, environment, injury histories, opinion on protection), but more in details. For example, to know how they protect themselves from unexpected falling could be a major difference from amateurs, because they have more experience to deal with such circumstance, and been taught in a practical way to avoid injures. A complete understanding through those in depth specialized information will help the whole design process moving forward.

6.2.3 Result from interview and questionnaire

As mentioned above, the first step interview have seven amateurs, the second step have nine subjects from professional sports men and women. All the subjects come

from Scandinavian area, and the age is between 19 and 52. The average height, weight of the male is 179cm, 75kg, and the female is 170cm, 60kg.

From Sports and environment aspect, all of subjects from amateur group doing multiple sports including, ski, snowboard, on land skiing/skating and cycling. The temperature when they usually do winter sports is beyond -20 ℃ to 0 ℃, however, the place they usually cycling is about 30 ℃ or more. Most amateurs start skiing when they were very young, about 9 years old in average, and taught by their parents or families. They not only perform one category of skiing or snowboarding, for example, downhill ski and free styling are two of most mentioned names. Another factor is that they seldom try very dangerous movements, which means for the highest air trick is about 3m from ground. However, the potential danger will comes from the high speed downhill skating, which is about 70 kM/h, and the collision between the rocks or tree brunches when fall down.

On the other hand, the professional group, 6 of them are only doing downhill ski for winter sports, and on land ski/skate for training. They spend more than3 hours each day for training no matter in winter or summer, both indoor and outdoor, which is far more than amateur group who are only spend one week per year during the winter, and no more than two hours each time. They have professional training equipment and coaching staff. The outdoor environment is similar to amateur group. For indoor training, back protection normally consider as unnecessary.
In addition, postures mentioned by interviewees that involve back movement are listed below:
Posture from cycling:
1. Get on/off bicycle
2. Accelerate
3. Relax
4. Uphill

Posture from skiing:
1. Put on boots
2. Sit on the lift
3. Regular ski
4. Skate

About injures and prevention aspect, the most mentioned injury area is shoulder, followed with coccyx. Scapula area takes the third place. Only one subject mentioned spine injury coursed by compression. The result is consistent with the statistic made in Switzerland, 2010 (bfu – Swiss Council for Accident Prevention, 2010).

There is only differences in the details when compare with fall down prevention postures between two groups. All of them using their buttocks, shoulders or lateral of the body land first rather than other sensitive or fragile body parts, for example, hands. However, the profession sportsman normally have a clearer sense when unpredictable falling down happens, they will add muscle tension and fully perform the protection posture under this circumstance. In a contrary, inexperienced skiers would easily get panic and not fully prepare the landing posture, therefore hurt themselves. However, in some case, for example when skier under a high speed skiing or fail to accomplish a complex air trick would still leads to inevitable injury or painful on the back part, no matter how he or she perform the protection posture. That is why back protection needed.
Attitude towards back protection is another important area during the interview. In general, from the interview, everyone wears helmet and goggles, which is also consistence with previous pre study result. The attitude towards using back protection is depending on individuals. The most mentioned reasons including, price, and the frequency of sports, as well as perspiration and individual injury experience.

For the amateur users, they did not start using back protection after one or more than two years when they start to ski, because during this “learning phase”, they usually chose gentle slope and moderate movement. Even if they fell down, it would not lead them serious injuries at least on the back. After “learning phase”, some of them start consider more protection on elbows, knees, as well as shoulder and back part, because the progressively understanding of the danger, together with advices from friends and coaches.

On the other hand, within the professional group, almost everyone using back protection, because they aware the dangerous in the first place, or just follow the regulation from club.

For perspiration issue, most of users grade it as “warm but acceptable”, because sometimes warm is profitable when doing winter sports. However, there are more complaining from professional sports, because of the long time training. They all agree the bottom line of ventilation requirement is warm but no sweaty feelings.

Price always the central part of the debt, “the cheaper the better” for amateur users, because they do not using it very often, the idea price they expect is beyond 500 Swedish Konor with relatively good protection. Profession group have higher tolerance with the price, from 500 to 2000 are both acceptable, because they more focus on safety and comfort. Expect from self-purchasing, many of users mentioned they get their back protector as a gift. Otherwise, they have no intention to buy them.

The attitude towards fitting is generally positive, but still there are complains like, “It slips upward when sit down”, “does not follow the twist movement”, “It restrained Head movement sometimes”, “it would be better if it can support the back or waist Weight”. Another interesting fact is, if the user is too thin, the protector will slip up and down.

About the weight of the protection, most of users cannot feel it when doing sports. Only 2 female interviewees mentioned that it is too heavy to wear.

The graphic design and appearance of the back protection sometimes neglected by the consumer, because in spite of shape and graphic design, comfort is the most important element in their perspective. However, there are some different opinions from interviewees who are design students. For example, the appearance of the back protection should express the safety and comfortable feelings, in order to attract customers in the first place. Back protection cannot be seen in normal situation is another key factor that cause customer ignore appearance aspect. However, during “after ski”[2], the back protections have great chances to exposure to others. It somehow makes the outlook more important.

6.3 Observation

When designing a comfortable and non-restrict back protection, the designer needs to fully understand the movement pattern when athletes doing sports, not only from literature but also from practical. Because of that, observation method became a first choice to accomplish the goal.

6.3.1 Prerequisites

There are 6 participants for the posture observation study and video recordings. They are four male and two female, three of them are amateur, and other three are former ski jump athlete and professional sportsman.
The movement task chose to be observed is based on the answer from the questionnaire “Is there any movement that you need to twist or bend your back?” from the interview step. For ski, except the normal ski posture, movement like putting on ski boots and sitting on ski lift are mentioned most from the interviewees. On the other hand, for bicycle riding, during accelerate, uphill, and normal riding will somehow cause back movement in different levels. In addition, falling down from ski or bicycle will definitely involve back movement, but due to its complicated process

[2] an activity people gather around drinking and talking after skiing, usually without ski jackets

and different circumstance, it will study by simulating and recapping scene based on individual's experience.

In order to simplify the spine for observation and measurement, the spine can be seen as five isolated parts according to the anatomy, which is cervical vertebrae, thoracic vertebrae, lumbar vertebrae, sacrum, and coccyx. For the back part, only thoracic vertebrae, lumbar vertebrae, and sacrum are participant in bend and rotation movement. Therefore, the rotation angle between the three sections mentioned above will be the main subjects to study with.

6.3.2 Result

When comparing 3 basic riding posture, from the side view [figure 8], the angle between thoracic vertebrae and lumbar vertebrae changes between 13 degree to 34 degree, as well as 19degree to 23 degree between thoracic vertebrae and lumbar vertebrae. From back view, the spine bending angles swifts in YZ plane [figure 9]are no more than 8 degree.
For the on land skating observation study, as can be seen from figure 10, the largest angle between thoracic vertebrae and lumbar vertebrae is 30 degree, and 64 degree between lumbar vertebrae and sacrum.

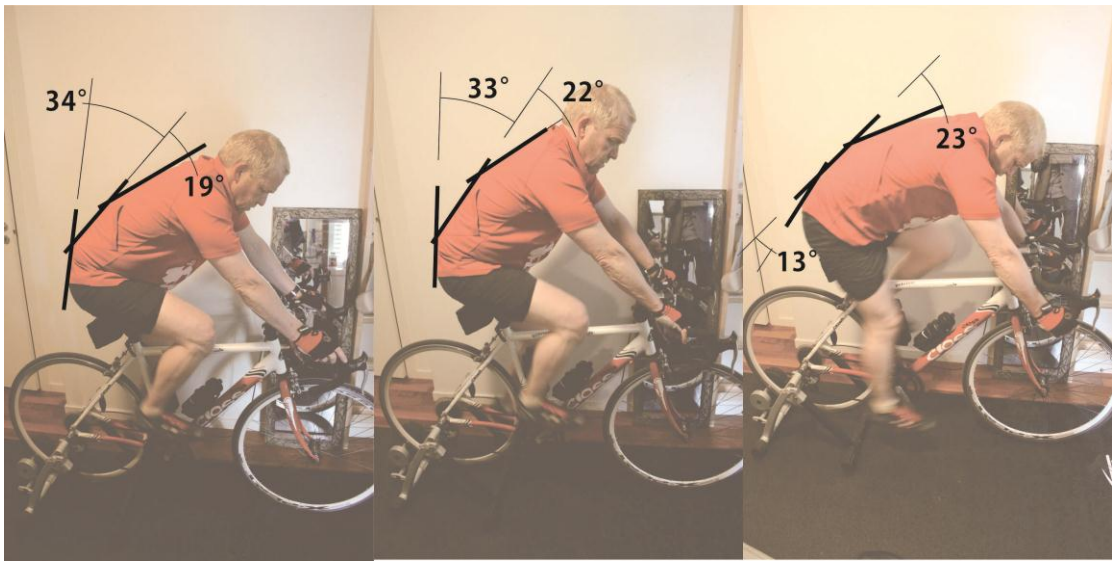


Figure 8 bike observation study result-lateral view

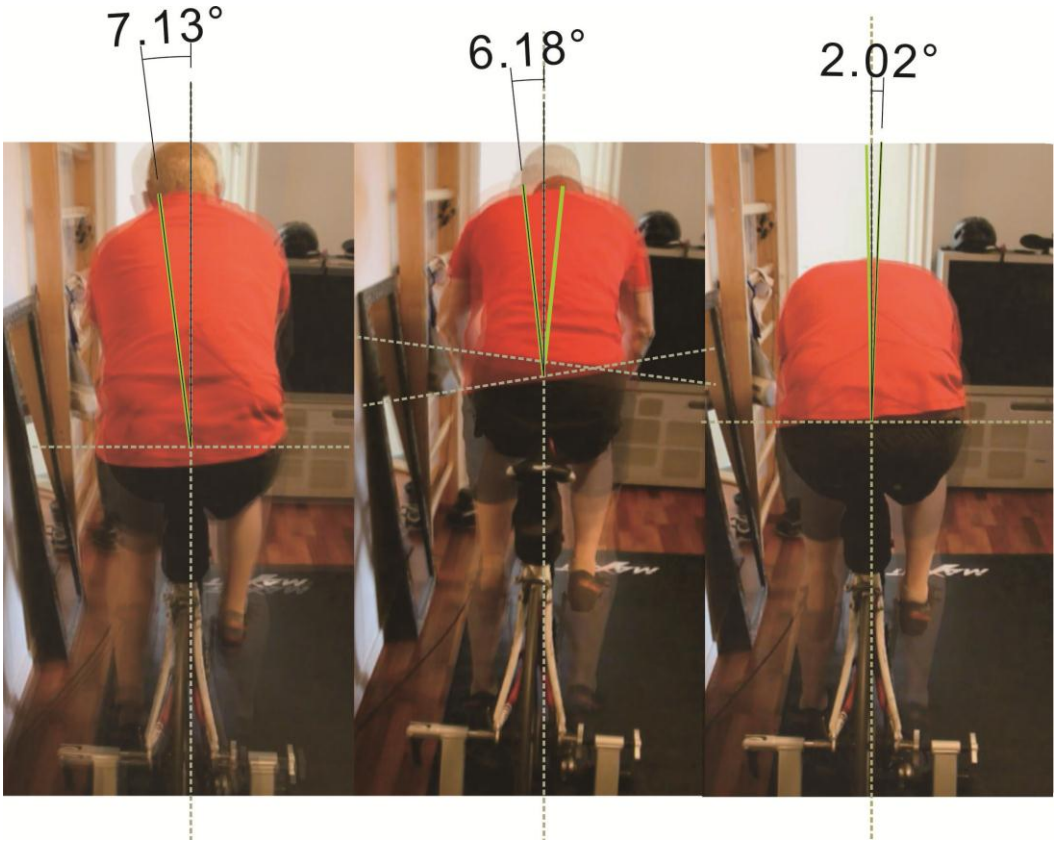


Figure 9 bike observation study-2 back view

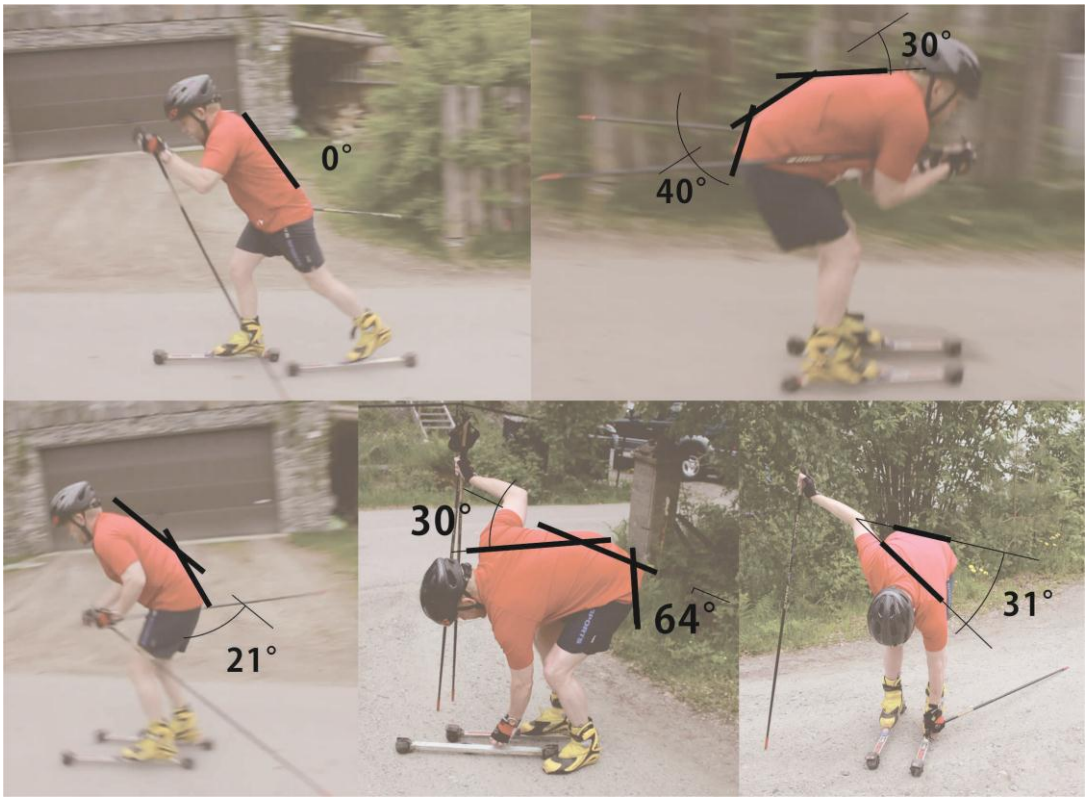


Figure 10 on land skating observation study

6.3.3 Discussion

Because of the limitation as season and location issue, video recording with 3 amateurs is using empty gestures without any equipment wore on, which was lead certain Inaccurate data. In addition, because all the movements are recorded by cameras in different settings, there must be some inevitable inaccuracy caused by angle or resolution issues. More important is, the whole observation and analysis procedure based on human being's personal observation and measurement experience, but the capacity of information is tremendous "overload" for a most experienced observer, which means many details were lost during the observation and analysis. In a conclusion, the result from traditional observation method is inaccurate and lack of details. It is far beyond the design demand, which is to understand the back movement pattern completely. So that, some more advanced method needs to be explored.

6.4 Motion Capture

As it mentioned above, the traditional method to analysis movement pattern is to observe by using naked eye and assisted with camera. This method is adequate for limbs or the whole body, whose movements are relatively obvious. However, when it comes to the back, one can still roughly measure the angle of spine rotation when subject doing bend and twist (as mentioned in previous section), but lack of details, for example, the relationship between each spine sections. Moreover, as David A.Winter said in 2009, a complete and accurate quantitative description of the simplest movement requires a huge volume of data and a large number of calculations, resulting in an enormous number of graphic plots (David A. Winter, 2009). Imprecision is always occurred because of only using camera and naked eyes to capture the complex movement pattern of the back muscle and spine structures. To sum up, the traditional observation method cannot fulfill the design demand of the understanding the back movement pattern, so a new method, using motion capture system is introduced to solve the problem.

6.4.1 **Motion Capture system**

A Motion Analysis Eagle Digital System attached with specific software is especially made for analyzing complicated and dynamic body movement, and transfer them into clear data and plot (Motion Analysis Corporation, 2009) . That is why this method was applied in this thesis work.

In general, the Motion Analysis Eagle Digital System is using multiple cameras to trace the reflected light from several reflector balls, which are sticking on certain parts of experiment subject, in order to capture the movement pattern of the certain parts or a big picture of body movement from experiment subject. After that, the data can be further used in 3D modeling software, thus provide an easy way to build computer models when in the design phase. (Motion Analysis Corporation, 2009) Therefor, Those features make the Motion Analysis Eagle Digital System as a perfect tool for capturing the movement pattern of back movement when skiing and cycling.

Due to some reason, the experiment was hold in a laboratory located in Human Science Faculty of Design, Kyushu university, Fukuoka, Japan. [Figure 11] It belongs to Professor Tochihara Yutaka, a specialist on motion capture and environment study.

Figure 11 a picture of lab of Professor Tochihara Yutaka in Human Science Faculty of Design, Kyushu University, Fukuoka, Japan

6.4.2 **Preparation**

Before perform the experiment, related preparation need to be settled. Preparation stage divided into 3 subtasks, the first task is to select movement task to perform the

experiment. Then, ensure the reflector location on test subject. After that, setup and calibrate the equipment would be the final stage of preparation.

6.4.2.1 Movement Selection

The purpose of understanding back movement pattern is to eliminate restrain caused by the back protector when user skiing and cycling. When comes to select the study movements, those postures that involve miscellaneous back muscle movement, spine rotation and scapula ups and downs would be the first choice. Though out the interview step, there are several postures need be pointed out according to the question in the questionnaire, “Is there any movement that you need to twist or bend your back? And how?”

Posture from cycling:

5. Get on/off bicycle
6. Accelerate
7. Relax
8. Uphill

Posture from skiing:

5. Put on boots
6. Sit on the lift
7. Regular ski
8. Skate

In spite of those postures mentioned above, some basic movements that reach physical limits are considered also important as understanding the back movement pattern. There are two reasons for study basic back movement. First, through the observation, all the back movements during the sports are within these basic physical limits movements. Besides, it simplifies and makes the data much easier to compare with, which save times for further research. Secondly, the unrestricted basic movement will be one of the most important facts that influence their purchase behavior and feeling, when consumers first try on the product. The basic back movement, which mentioned before in pre study phase are listed below.

Basic back movements:

1. flexion and extension
2. lateral bending
3. (axial) rotation

6.4.2.2 Reflector location

When comes to ensure the reflector location, It still different from normal motion capture experiment routines.

As mentioned above, MA system always used for whole body motion capture or movements focus on the limbs. It is an innovation to use MA system on the back part, so there is no such reference to follow when placing the reflective markers. However, there are some examples uses the Helen Hayes (both the static and dynamic) marker

sets [Figure12], which consider as a start point for this task. Furthermore, there are some basic rules mention by MA reference book (Motion Analysis Corporation, 2009), for example, first, reflector balls need to place on some points which have relative obvious displacement. Secondly, the reflector placement need based on the purpose of the research. The purpose here implies to "understanding the back movement pattern and designing a back protector that perfectly fits human body yet restrain body movement."

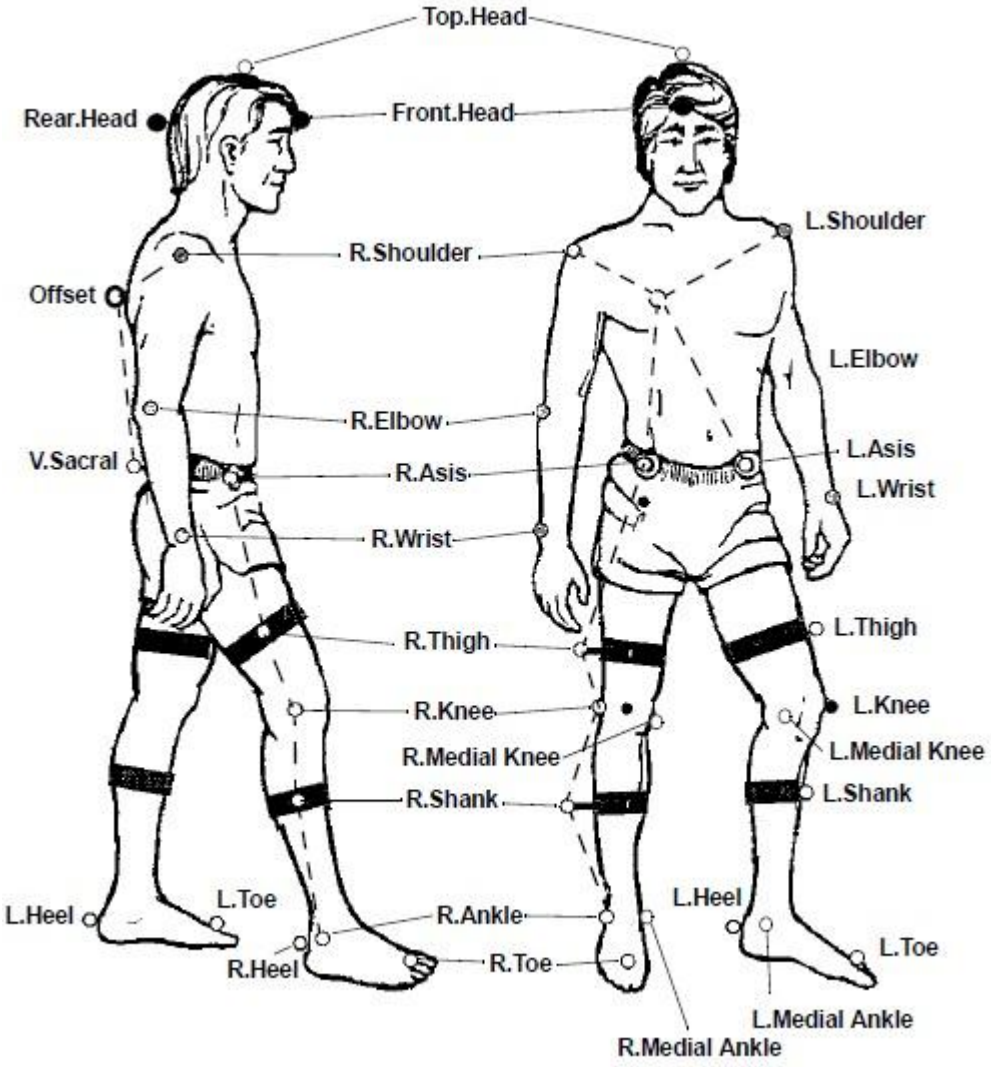


Figure 12 Helen Hayes Marker Set Placement

According to the reference mentioned above, when comes to this experiment, the final reflector allocation [Figure13] have some additions and subtractions on the basis of Helen Hayes marker sets. It made based on three factors, first, the anatomy of human back, including spine and muscle structure. Secondly, area needs to be covered because of impact protective reason. Thirdly, the understanding of the whole body movement.

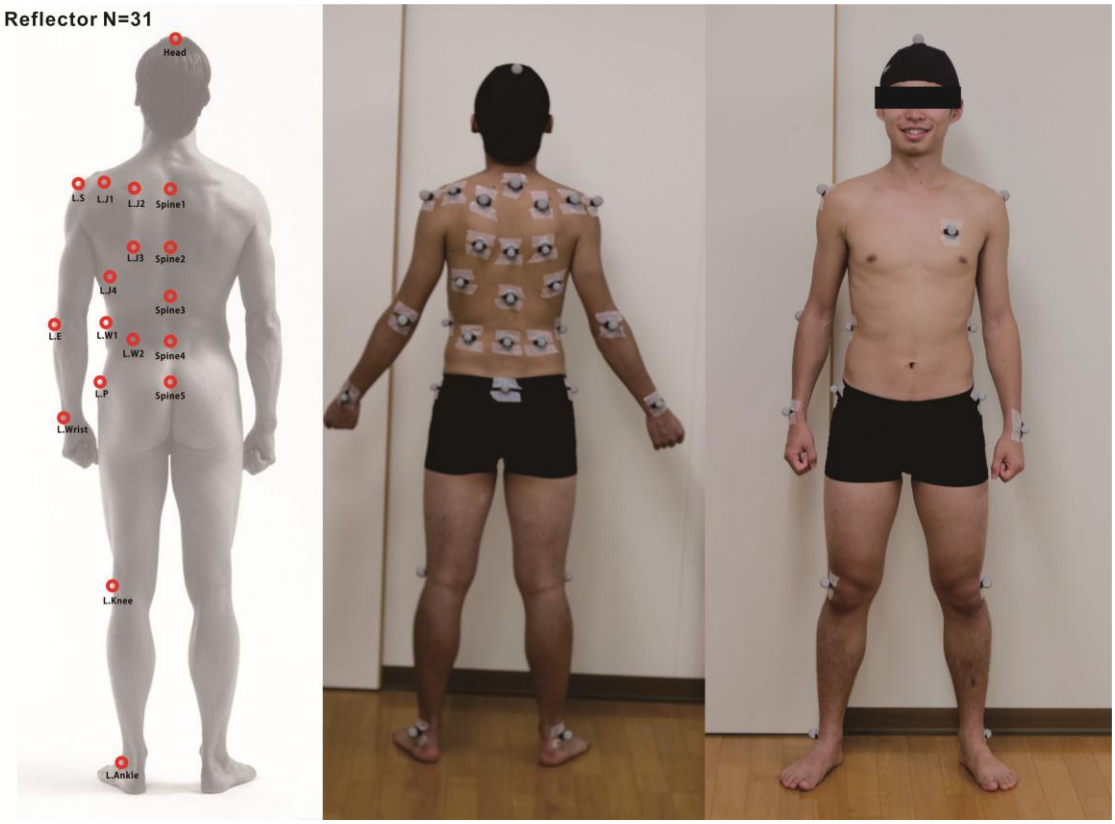


Figure 13 final reflector location

6.4.2.3 Axes System

Before setup the equipment, an Axes system, which was recommended to applied in the motion analysis system was studied.

Although, there are several axes reference systems are frequently adapted in the motion analysis systems, for purpose of convenience, the Global Reference System(GRS) will be consistently used in this experiment: X is the forward/back ward direction, Y is the vertical (gravitational) axis, and Z is the left/right (medial/lateral) axis(David A. Winter,2009)

6.4.2.4 Equipment Calibration

For motion capture involving only one subject, where the occlusion of markers is not a problem, six cameras may be adequate. When more than 5 or 6 cameras see the same marker, the accuracy of tracking is not increased and computation time increases. (EVaRT5.0 User's Manual, 2006). Because the Cameras are not fixed in their laboratory, the first step of the setup experimental equipment is rearranging the camera in order to best capture the movement, therefore calibrate the GRS. After calibration finished, the subject need to pose an initial posture, to help the laboratory assistant build a reference skeleton in relative software. Therefore, when the subject performs his or her movement tasks, computer will recognize reflectors rely on corresponding joints position in basic skeleton system instead of a group of unorganized dots. It save times when sort out the data output after the experiment.

6.4.3 Motion Capture Experiment

The experiment process is relatively easier to operate compare to preparation stage. The well-prepared subject with all planned reflectors stuck on his or her body was asked to perform the motion tasks mentioned above in a certain order, and each of task need to be performed twice in order to minimize the deviation. Due to the time limit, only one subject, male, 175cm height is participated in the motion capture experiment. All the documents are recorded by a separated camera.

6.4.4 Data Transfer

All the data collected from the experiment is handled by software called “EVaRT5”. It not only output videos and simple animations, but also manually transfers the information of displacement of coordinates from each marker into tables and plots. Then, animation or three-dimensional model can be rebuild based on the data from the tables and plots in Computer Aid Design software whenever needed. After that, all the further measurement or modeling can be made within the CAD software.

6.4.5 Result and Discussion

After straighten out the data, the rebuild three-dimensional model are showing in Figure14, in CAD platform Rhino.

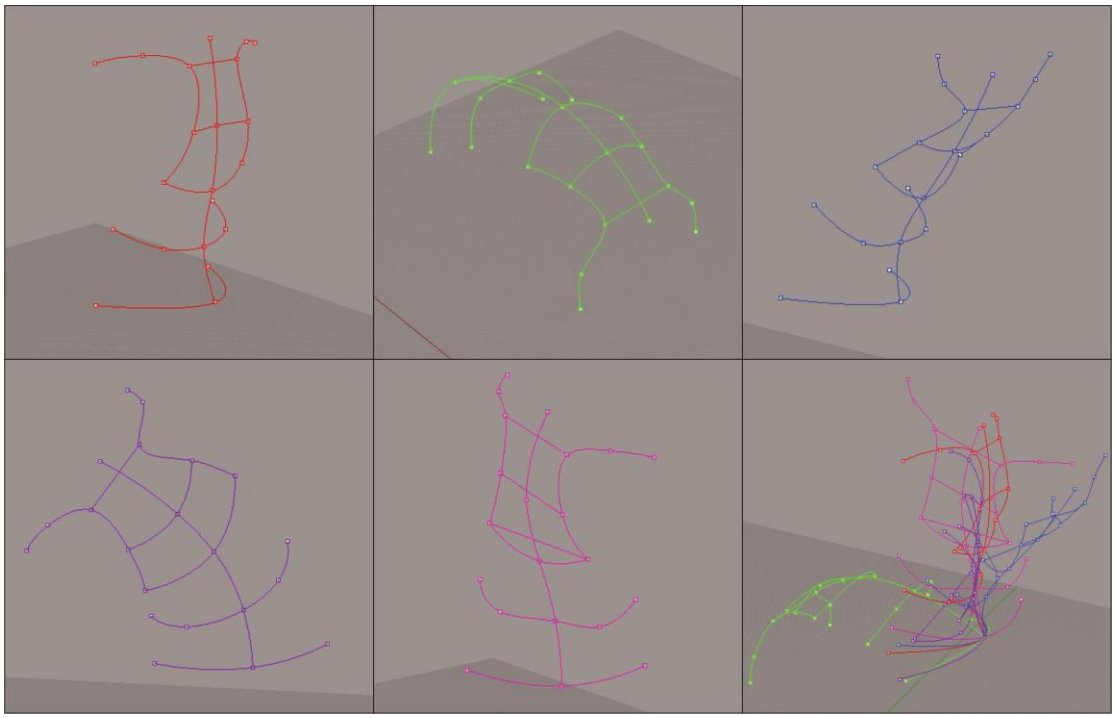


Figure 14 data from Motion Capture experiment, reunion in Rhino platform

The red one indicate the upright posture, the blue is backwards bend (spinal extension), the green is forwards bending (spinal flexion), purple is Lateral bending, pink is twisting(spinal axial rotation).

When measuring the length changes of the "spine curves" in different posture, some unexpected result was found. The result of the measurement list below:

Red: 48.98cm

Blue: 43.52cm

Green: 62.54cm

Purple: 48.77cm

Pink: 50.05cm

The spine would never change lengths between about 5 to 15cm, according to literature study or conventional reasoning. Thus, after observation from the video materials shot at the scenes, instead of the spinal length change, the skin covers the spine area has extended and contracted together with the back movement. It can be seen from figure 15, by the regions divided in the experiment, the blue and red regions have contracted, yet the green and purple regions have extended. The blue region, which refer to skins above cervical spine area have shrunk about 4cm during the bend forward posture. The purple one, which refers to skins above lumbar spine

area, has more obvious extension than green area (skins above lower thoracic area) did. It means that the skin in spine area, have extended towards two directions, cranial and caudal, when bending forward, and the skin in the middle have less extension than those in the both ends. Similar movement pattern can be found in other back movement as well.

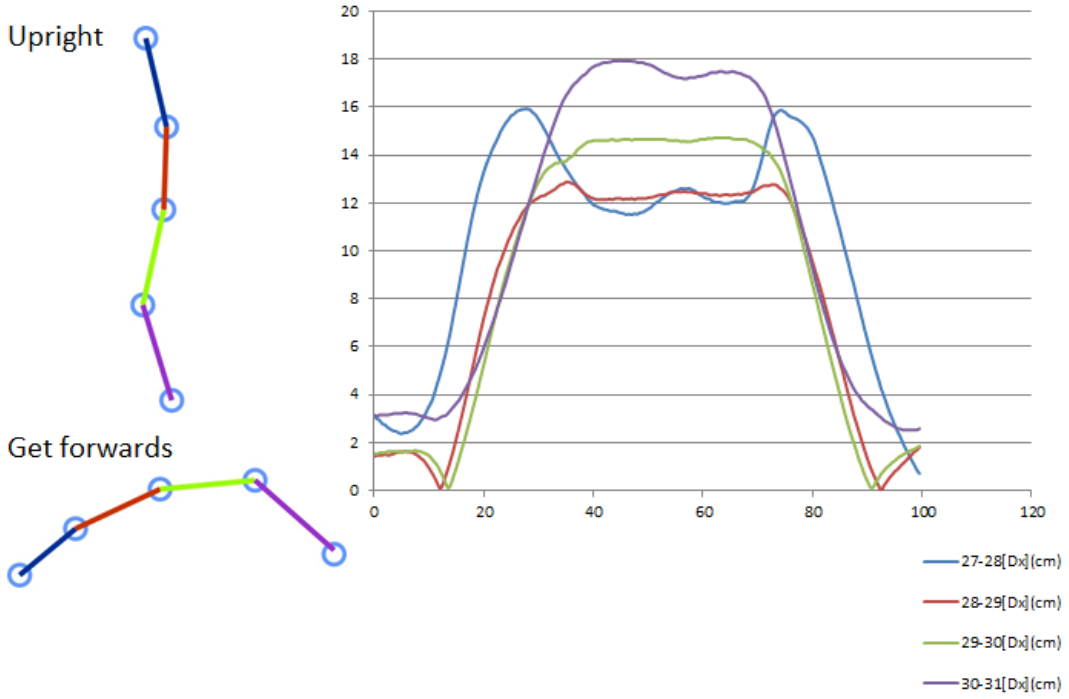


Figure 15 data analysis on skin contraction

However, this movement pattern will lead comfortlessness to those who wearing one block traditional back protection. According to the market research, most of the back protection are formed by either one block or several pieces of protection modules. Those protections usually cling to the back curve when the user in upright posture, however, when he or she bending, the inductile protection could not follow because the back skin curve is extended. Although some of the material using soft or thermo-shaped material, which, but most of them lack of good ductility. Normally, the related loose shoulder straps help the back protection release some of the restrain feeling. It is a solution, but from safety perspective, it is not a sensible solution.
To find a new material with great flexibility, elasticity and ductility, etc., would be a good solution, but for this thesis work, more solution will be explored from structure angle.

Before the idea generation phase, there are some guidelines and inspirations were gathered from the motion capture experiment. For example, according to the back movement pattern and the natural “S” form spine curvature, the back protection should be cut at least into 3 section to ensure the freedom of basic back movement. That is because the back skin move towards two direction when individual doing

bending movement, assuming the material is non-extendable, there are should be at least 2 unconnected protection modules, and each of them covers upper and lower part of spine area. However, 2 protection modules will never follow the "S" curve which spine have. That is why the third part of unconnected protection is needed.

When compared with upright posture, the alteration of skin length during bending forwards and backwards is between 13.56cm to -5.46cm. It brings a trick question to Structure exploration, if the protection will keep the spine area fully covered. It means that the protection not only needs to follow the movement, but also cover the spaces when the unconnected protection modules leave during the movement.

6.5 Biomechanics

According to the interview, the most common situation causes back injuries during skiing and cycling is fall from height /jump. Therefore, the impact and energy feedback from falling ground needs to be studied to ensure the protective level of the back protection. How much energy needs to be absorbed by protector in order to avoid injury will be the topic of this biomechanical study.

6.5.1 Biomechanical calculation

The context of the biomechanical calculation was set according to interview, the scene is described the moment that a male athlete was falling off from his moving bicycle.
The study object is 175cm height, 70kg weight (upper body 40kg). The distance between the ground and his center of gravity is 130cm. according to the interview, the highest speed for riding a bicycle is 70km/h (19m/s).g=10.
So the impact force when he fall down from the bicycle F will be:
According to law of conservation of momentum, $1/2mv^2=mgh$
The final velocity in horizontal is $V_{1t}=\sqrt{2gh}= \sqrt{(2 \times 10 \times 1.3)}=5$ m/s
According to momentum theorem, $F_1t= mv$
Here, we minimize the t=0.1s, so, $F_1= mv_{1t}/t=70\times5/0.1=3500N$
$F_2=mv_2/t=70\times19/0.1=13300N$
The kinetic energy transfer from gravitational potential energy when falling down is
$Ep_1=m_{upp}gh=40*10*1.3=520J$
The center of gravity higher from ground, the final force/impact is larger.

According to the interview, the highest jump during cross country ski is no more than 3m. Therefore, the force will be,

According to law of conservation of momentum, $1/2mv^2=mgh$
The final velocity in horizontal is $V_{1t}=\sqrt{2gh}= \sqrt{(2 \times 10 \times 4.3)}=9.2$ m/s
According to momentum theorem, $F_1t= mv$
Here, we minimize the t=0.1s, so, $F_1= mv_{1t}/t=70\times9.2/0.1=6400N$
$F_2=mv_2/t=70\times19/0.1=13300N$
The kinetic energy transfer from gravitational potential energy when falling down is
$Ep_1=m_{upp}gh= 40*10*4.3=1720J$

6.5.2 Discussion

According to the pre study, "*The average peak reaction force for the thoracic failure tests was 4720±1340 N, and the average peak reaction force for the lumbar failure tests was 4650±1590 N.*" (Cameron R et al., 2007). When an athlete fall from 130cm height, the impact force 3500N is slightly larger than 4720-1340=3380N and 4650-1590=3060N. When a skier fall from 3m height, 6400N is almost doubled the spine injury threshold value. If consider the collision from bumpy ground surface, e.g. rocks and tree brunches, which will affected by speed issues, the force will be even larger. In a conclusion, according our target group (sports man with not many high jump movement involved), the back protection needs absorb at least approximately 3400N impact force. After discussion with company, at this stage of the product development process, the bar was set on 5000N to be in a safe way.

7 Design Phase

Due to the 3 times goal changes, different from normal design phase, it was divided into 3 idea generation steps and 2 concept development steps. Material discussion is a supplementary part to design phase.

7.1 Idea Generation Round 1

The first round idea generation was done before the EMG test and Motion Analysis experiment.

So the main reference was based on the result from interview and observation. There are 2 reasons why the idea generation start in such period. First, for a sports related product, with such complex ergonomic study involved, it is better to start mock-up as earlier as possible. After several round of test and modification the physical model, a better result can be found. Secondly, there was no other methods can be used at that time except mock-up, because the resource in Chalmers or the company is relatively limited.

The first round design idea generation is focused on protective material structure and arrangement. According to the pre-study and interview, the shoulder, scapula area and tailbone area have the highest probabilities to get bumped or injured when compare with other area on the back. Beyond them, the entire spine area is the primarily target that needs to be protected.

7.1.1 Image Board

Except from function requirement, there are still some appearance issues needs to be considered. For this concept development stage, the company did not set any mandatory requirement on styling and shape, but still there are some key words needs to be fulfilled as a sports related product, for instance, passion, dynamic and safety [Figure16].

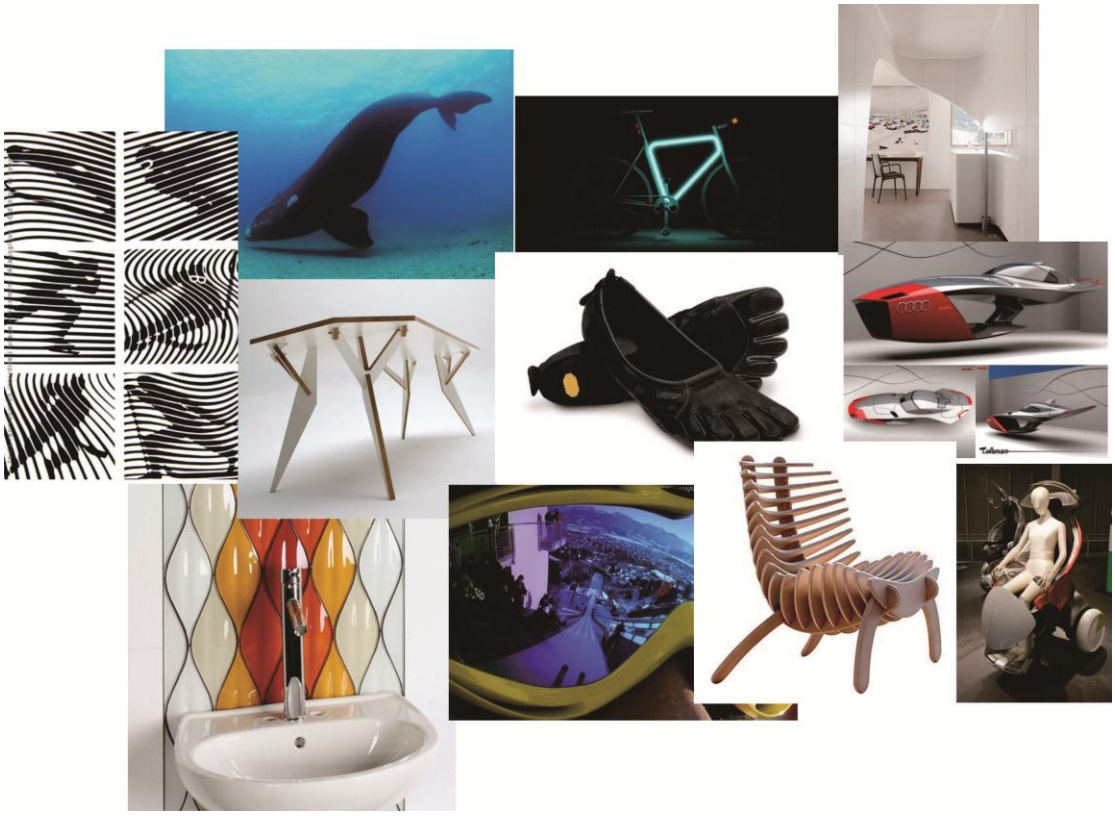


Figure 16 image board1

7.1.2 Ideas

Several free hand sketches were first made based on the functional, esthetical requirement, and inspiration from image board [Figure16].
The first three are quite similar [Figure17], but with different shape and arrangement. They all using traditional hard shell (white pieces) combine with soft pad material (orange pieces). The protection is normally constitute by 5 pieces, 2 symmetry scapula protection, and tree pieces of spine protection covers from the end of the cervical vertebra to the coccyx. The shape flows alongside the boundary of scapula, and protect the important organ, like kidneys. The three separate pieces formed spine area protection, which allow the users move their torso freely.

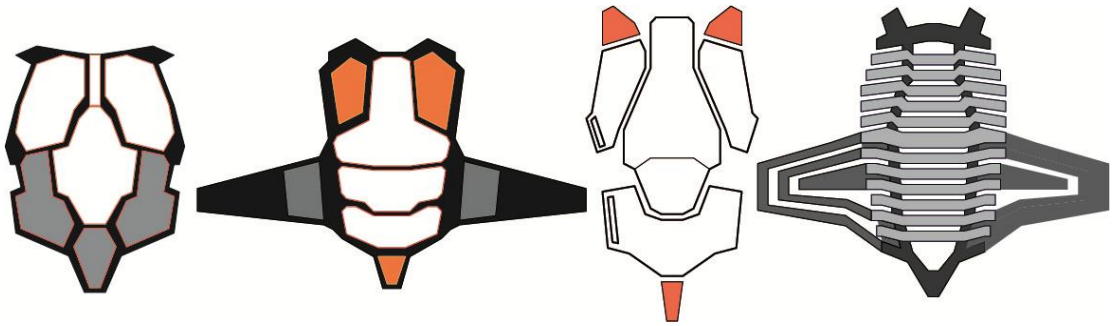


Figure 17 4 ideas from Idea generation 1

The last one was called “fish bone” [Figure17]. As can be seen from the name, it was inspirited by fish bone. Any kind of soft material that can fulfill safety requirement can be used in this structure. Because of this unique parameter, there are three advantages than the first three. First, using the soft material somehow adds flexibility and comfort when user wearing them. Secondly, the fence structure can provide vertical impact resistance, but have no influence on horizontal bending or twisting. Thirdly, fence structure will also dramatically improve the heat dissipation, and reduce perspiration. For the last, the unique shape can distinguish itself from normal back protection, which will bring commercial benefit. However, despite all the positive aspects, there are still some limitations. For example, the material requirement and production costs for the fish bone structure will be much higher than the normal one. The worse thing is, the spaces between the fences structures will became a potential danger when user collision with penetrating and sharp object, like branch or stone. As a result, this concept is innovative yet immature. It will need more research on material selection and structural Mechanics.

7.1.3 Concept Evaluation

After balance the advantage and disadvantage each concept have, the company suggest focus on first three concepts, and keep developing the “fish bone”. The first three is functional, cost-efficiency, and easy to implement with existing technology, which will be a great start point when starting a new back protection brand. On another hand, “fish bone” with its unique design and comfort wearing experience may also have a great advantage in the market, yet there are fatal flaws beyond the design, so keep the idea alive and keep changing and developing consider as a decent solution.

7.1.4 Mockup

Due to the schedule, at least one mockup need to be made before the trip to Japan for motion capture experiment. Idea number three was chosen to make the mockup [Figure18]. Paperboard was used in the mockup making for this model, because it is tough enough to simulate hard shell material in this case.

The mockup fit the back very well, but some area still smaller than expected, leaving some places uncovered. However, the result is not important any further, due to the

changes happened after the trip back from Japan.

Figure 18 paperboard mockup

7.2 Idea Generation Round 2

From the beginning, there is no specific requirement on shape or appearance from company. However, along with the design process moving on, the founder start get in touch with some potential partner or investor. Accordingly, the goal of this Master Thesis became much clearer than the initial one. After that, one of their potential investor Helly Hansen A S have some interest in combine the back protector with their newly developed sports underwear, and the protective cloth should only cover spine area will be enough for their first stage cooperation. Because of that, the concept needs to change partly or completely to fulfill the new requirement.

The new goal set a higher level of comfort but less restriction compare to the old one, because the protection needs somehow combine with sports underwear instead of tied on outside the garment. Another fact is the protection need to be washable, antibacterial or removable. Protection from penetration became less important than before, because the whole protection will be wear beneath the garment. Besides the changes, most of the requirements still affect, and the research done before still consider as applicable.

Through the whole concept development process, those concepts developed in the first round of idea generation, e.g. “fishbone”, still have positive contribution to the idea generation afterwards.

7.2.1 Ideas

After clarify the new goal, some ideas are drew up according to the new requirement.

The “wave”, ideas comes from the arch bridge in ancient China. There are similar structure used in shoe shock- absorbing technology. The interconnected arch can absorb forces come from different angle [Figure 19]. Unfortunately, this structure has problem to follow the underwear when individual bend forward.

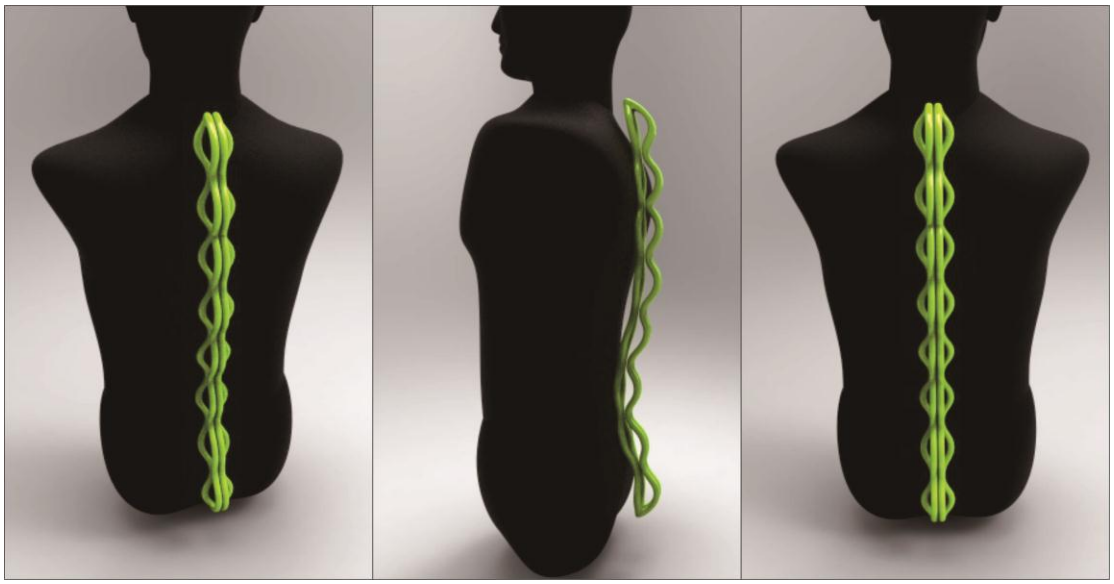


Figure 19 idea “wave” model

The second idea use small protective modules, e.g. square, instead of large pieces [Figure20]. There are 3 advantage by using this structure. First, each individual module using the same shape and material that saves production cost. Secondly, the modules are not connected with each other, which make the whole protection with less restrain and more comfort than traditional one. Thirdly, the space in between also promote the ventilation.

Figure 20 small protective modules and its variation

Because of these advantages mentioned above, this concept was selected to go deeper by exploring module geometry and arrangement aspects.

First variant was called “triangle honey cone” [Figure21], two stable structures construct a new reliable individual module, because when they comes together, they will have great resistance to impact towards back. There are almost no affect when

back bending or twisting. Besides, more ventilation holes was added not only because esthetics reason but also for reducing weight.

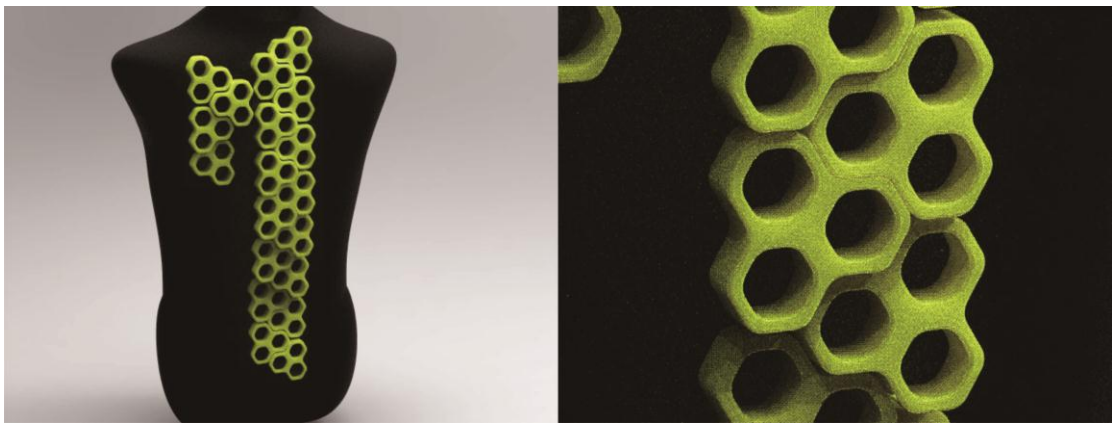


Figure 21 idea "triangle honey cone"

Second variant was "triangle air ball" [Figure 21]. This concept keeps triangle shape as the first one, but has slightly changes on detail. The individual module is constructed by 3 middle hollowed ball shape. In the middle, tubes in between connect them with each other. Thanks to this structure, the airflow can transfer and share the force when there are impacts on each module. Another advantage is there is less contact surface with body, which can increase the feeling of comfort when consumer wears it. In addition, the special shape make each module can closely contact yet not connected with each other. It will somehow eliminate the possibility of penetration by sharp object.

However, there are still some disadvantages like relatively high demand for material selection, have some problems for bending left and right, etc.

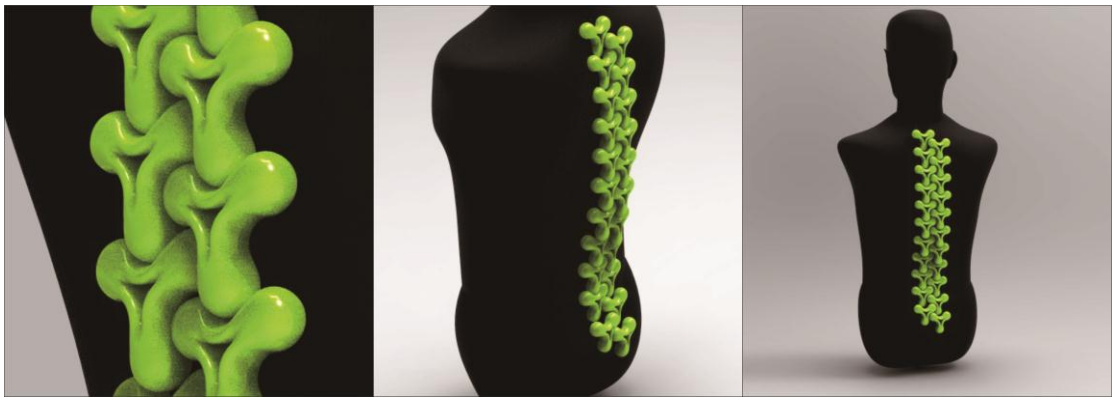


Figure 22 idea "triangle air ball"

There are other module shapes shown in the figure 23.

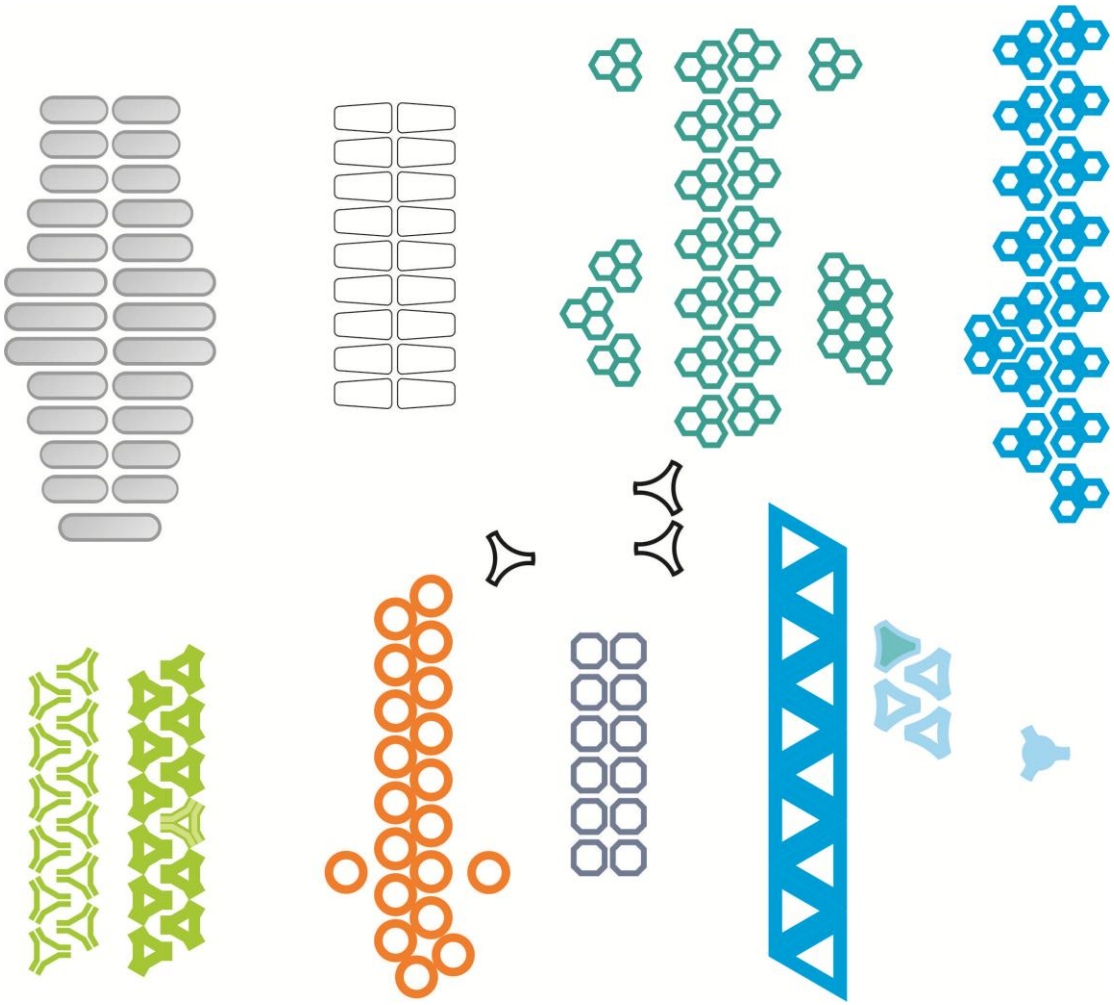


Figure 23 other ideas of module shapes

7.2.2 Mockup 2

In order to test the physical performance of the new concept, mockup test needs to perform again. For making the mockup, sports underwear and several individual protective module needs to be prepared.

7.2.2.1 HH sports Underwear

The test underwear is a product from Helly Hansen A S, with their Lefa[@] technology, which is the prototype that they intend to Implant with the back protection. The underwear is with extremely good elastic, and perfect fit with body. The male medium size was chose, because there are several subjects can fit in. the underwear is for up body, which covers the area between vertebrae C7 to S1 (may have discrepancy depending on individual)

7.2.2.2 Test subjects

Due to the special material in the underwear, two subjects are participated in the mockup test, one is 175cm, 65kg, who normally wears small medium size underwear, and another is 185cm, 75kg, who wears large medium size. Both of them can fit into the medium size of this type of sports underwear, so the protection performance on two different height subjects but same underwear needs to be studied.

7.2.2.3 Triangle honey cone modules

In order to simplify the mockup procedure, some details on individual module are eliminated, only basic shape is left [Figure24]. Foam are selected as the first material choice, because it easy to shape and lightweight. Each module is about 2 cm high, which is twice more higher than the requirement, due to the limited tools and material property of foam. However, it will not affect the result very much, because the purpose of this mockup test is to find out the physical ergonomic performance of the protection when it attached with sports underwear.

Figure 24 Triangle honey cone mockup and individual module

7.2.2.4 Result

After experience the mockup, both subject agree that there is no restrain when they bend fully forwards or backwards. Although, it can be seen from the figure 25, there are still little conflicts between individual modules during their lateral bending, but as

they said, it had nothing influence to the movement.

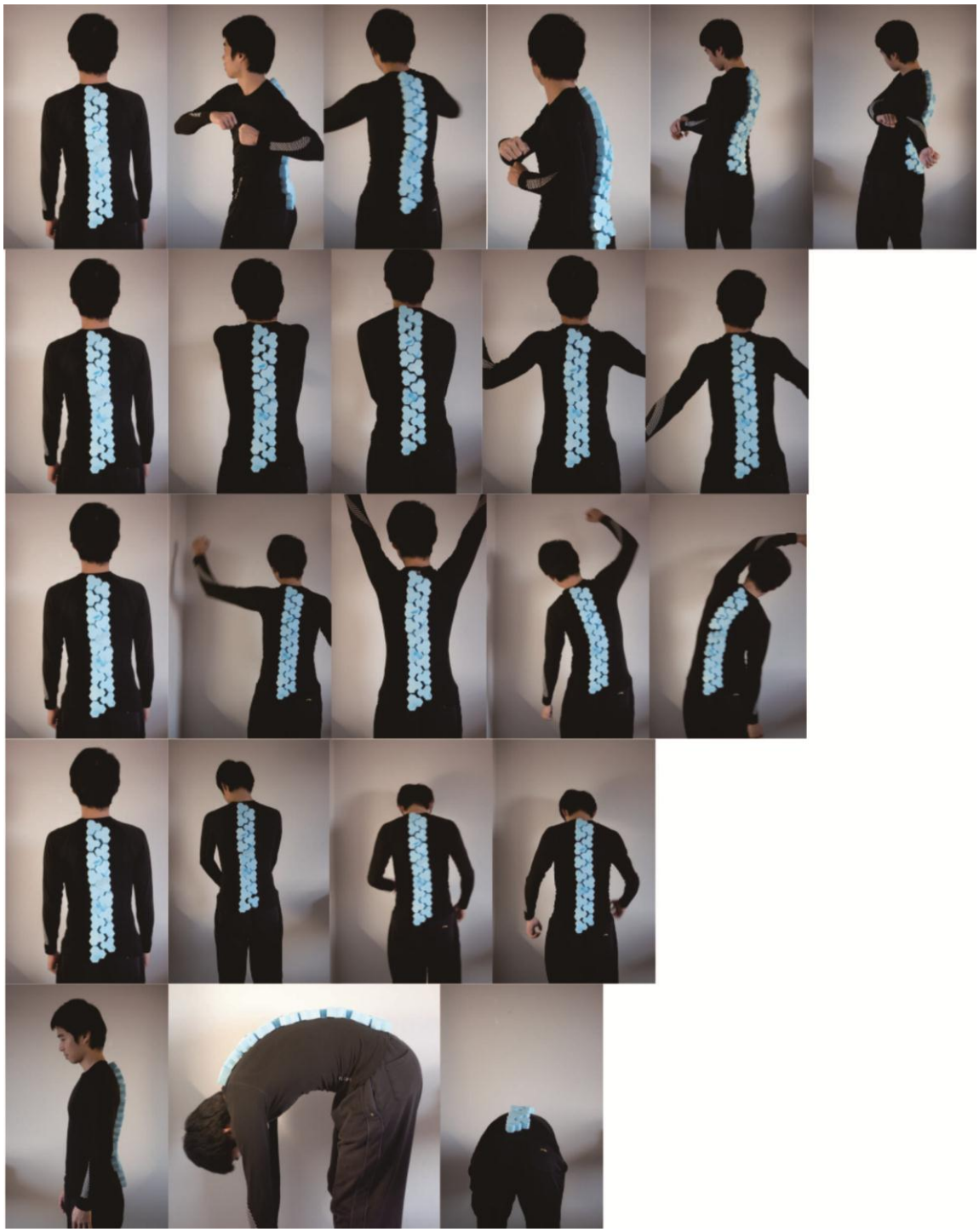


Figure 25 mockup movement test

The whole protection has adequate physical ergonomic performance on two subjects, but the in the protective aspect, the small gaps between each module became a potential danger for the users. Alongside with the extension of the underwear, the gap still can maintain within an acceptable range, when the small medium size subject wearing it on. However, when it comes to large medium size subject, the distance

between each module became even larger [Figure26]. Which means, it almost lost the protection function in these area because the elongation of the underwear.

Figure 26 large Medium size mockup test

In conclusion, the ergonomic test for concept “triangle honey cone modules” is satisfactory as the hypothesis for this concept. However, the superb elastic material made sports underwear cannot coexist with this structure. Therefore, those ideas developed based on this concept will not be further developed for this kind of underwear in this project.

It is noteworthy that, although the concept will not be adopted in this project, it does not mean this concept is a dead end for back protection development. There are still other application areas, for example, attaching them on less elastic material or for clothes used in sports environment without danger from sharp objects.

7.3 Idea Generation Round 3

In order to make the protection compatible with this superb elastic underwear, the idea generation process needs to be continued. The successful results from physical ergonomic test on “triangle honey cone modules” explore a new way of thinking, using small size protective module instead of traditional large blocks. Based on this thought, another round of idea generation is initiated.

7.3.1 Bionics

In the begin, more images are added to image board [Figure27], in order to get inspirations from some special structure which is tough enough to afford impact on one plane but flexible enough to bend freely on another plane. As can be seen from figure27, most of the structure comes from architecture figures.

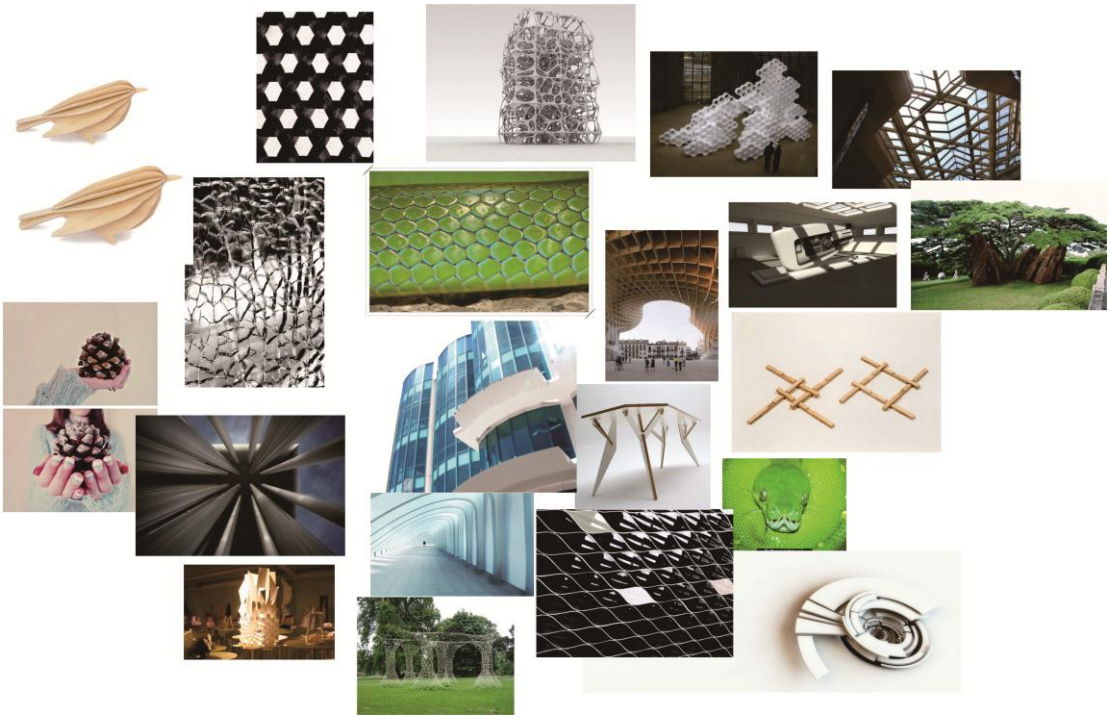


Figure 27 image board 2

However, there was no feasible concept comes out in that circumstance.
When the idea generation process stuck in the middle, new methods was used as mentioned before, bionics.

Human spine is an art of nature. To find a way to protect it and without restrain its natural movement, one needs to study structure, mechanism and working principle of similar organism.

There are many reptiles and fishes have scales which protect their bodies from complicate environment, but without restrain their movement. For example, snake, it serpentine like an “s” forms. The scales protect its body from rocks and earth. This structure is perfect for study in this case.
In order to study the scales, pictures and videos about fishes and reptiles body movement and scales structures are collected and observed.

7.3.2 Paper Sheet Mockup

After that, together with free hand sketches, paper sheet mockup was used as another inspiration tool to find the suitable structure free back movement and possible connection method between underwear and back protection. It not only saved more time than using 1:1 mockup in the first place, but also used a much easier and more

intuitive structure exploration by hand instead of complicated spatial imagination by brain.

As can be seen from figure 28, paper sheet was first cut into several same shapes, and then each group is arranged by different structure. Despite the scales structure, arch bridge shape and zigzag shape are applied in numbers of examples. It reinforces the resistance to the external impact, and increase the ventilation by reducing the contact surface with underwear.

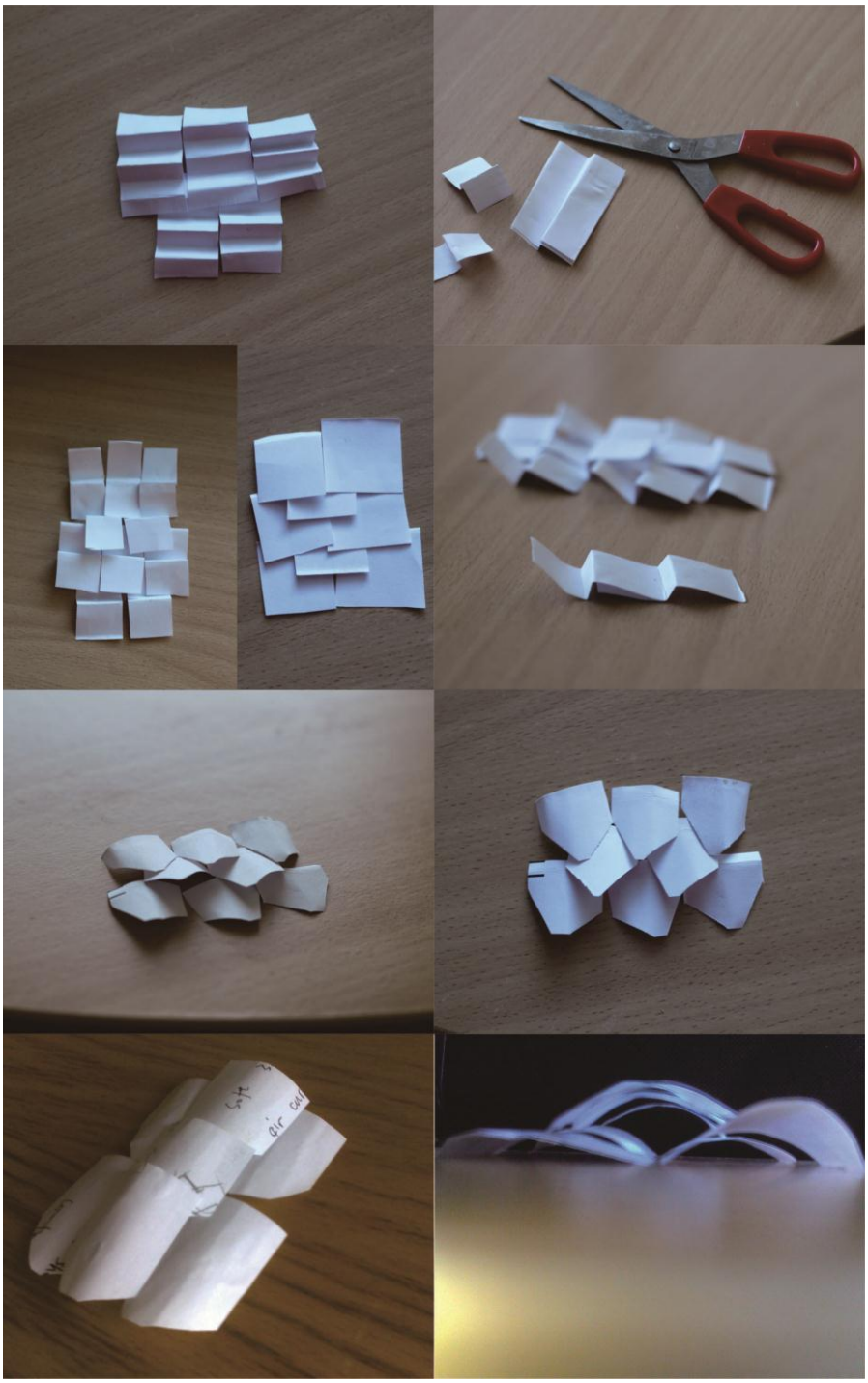


Figure 28 paper mockups

However, paper sheet mockup cannot replace 1:1 mockup, because it only build on 2 dimensional plane and only used for exploring structure and connection. Therefore, according to the result of paper sheet mockup, several new concepts are developed for further paperboard mockup and physical ergonomic test.

7.3.2 Concepts

Scales concept 1 [Figure 29] is directly transferred from paper sheet mockup. The whole protection is arrayed in a regular pattern, which is a two –three combination of the zigzag shape individual modules. The well-stacked zigzag modules form a non-gap defense against impact from different angles, no matter which direction the fabric of underwear will stretch with the body.

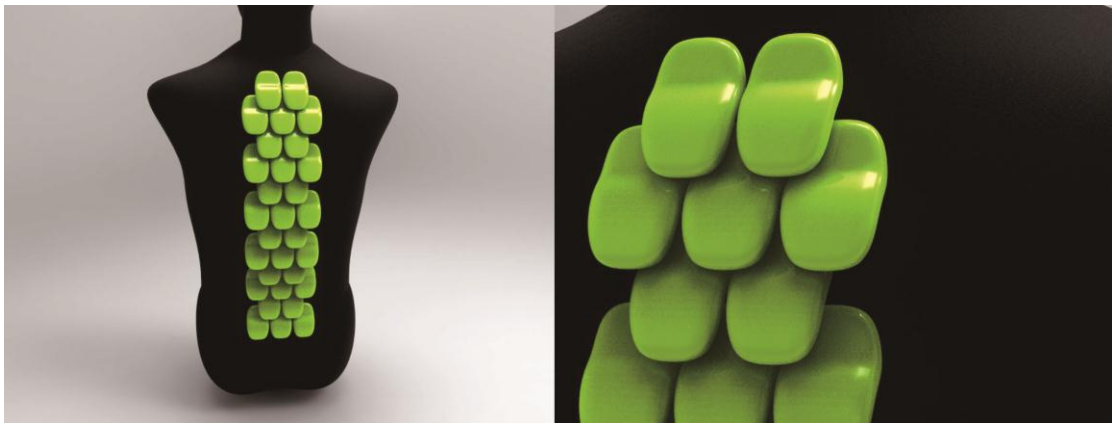


Figure 29 Scales concept 1, transferred from zigzag paper mockup

Scales concept 2 [Figure 30] is similar with concept 1. Both of them using the same "two-three combination" pattern, and constructing a non-gap protection. However, the individual module is slightly different. The more organic shape brings several benefits, for example, much fitter to the shape of human back skin, less confliction between modules during the back movement, etc.

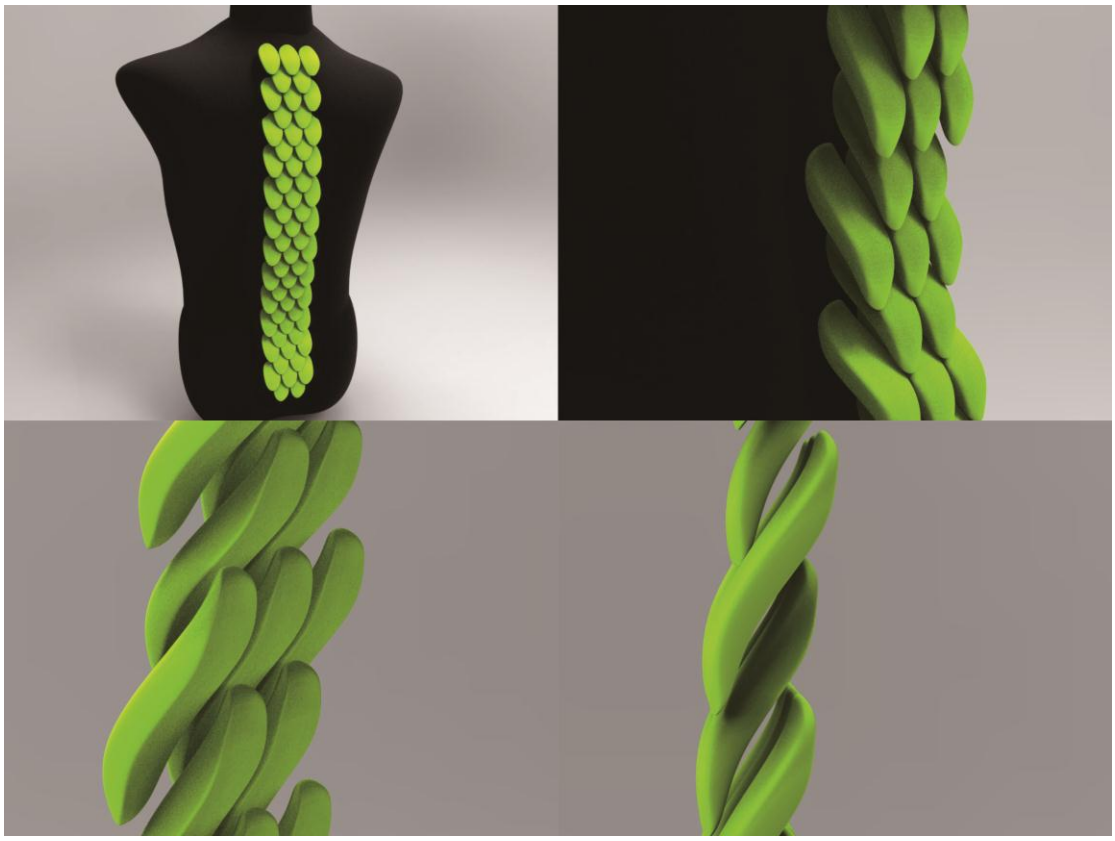


Figure 30 Scales concept 2

Despite of all the advantage, there are also flaws in these two similar concepts. The too specific and concrete expression of the scales shape has slightly lessened the attractiveness of the product. Because of that, the product fails to convey a feeling of sporty and passion to the custom.

7.3.4 Conclusion

During the “idea generation round3” stage, a new structure for no restraint body movement was found based on paper sheet mockup. It provides a new track to continue the design process. At meantime, several new concepts with different individual modules shapes were developed according to the new structure. However, flaws are still existed in these first few concepts of the new structure. In hence, more concepts need to be further developed in this track, by adding more details on shapes and sizes, and improving or changing the product appearance.

7.3 Concept Development Step1

After chosen the scales model as target model in concept development stage, more concepts would be bring out based on its structure.

7.3.1 Ideas

Bridge concept, from the overall appearance [Figure31], this concept is completely separated from the feeling of scales, but still a derivative of the scales concept. The advantage of this concept is that it still keeps the structure of scale in another perspective. The triple layered bridge-like individual modules form a sealed protection on spine area, yet have no affection on back movement at the same time. Each of bridge- shaped pieces are the same, they attached with each other as showed in figure 31. The two of them above, with one side joined with underwear, and leave another side attached on the middle of two parallel pieces below. This structure allows the fabric of the underwear be stretched horizontally. Simultaneously, the impact comes from outside can be transferred and absorbed by the three layered bridge arch shape. Another fact is that this structure is distributed as good as the vertebra, which can provide a more efficient protection compared with regular scales concept model. There are also limitations on this concept, for example, after lose the scale shape, the expansibility of the protection became impossible. Although, at that time, the client only emphasized protection on spine area, lacking of expansibility to cover scapula and kidney area can be still work for this project.

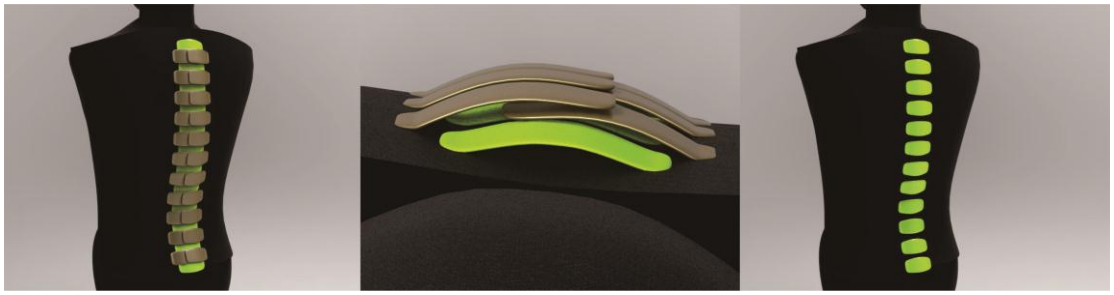


Figure 31 Bridge concept and its details

Scute concept, from the first glance [Figure 32], it expresses the similar structure as initial scales concept model. The only change is the shape of the individual modules. The reason why using hexagon shape instead of “scales” shape are not only consider from aesthetics perspective, but also from functional aspect. The hexagon or honey cone structure has certain stability when it suffers impact from different angles. In addition, hexagon covers more area/more volume with less material compare with other shapes (Morgan, F. 1999), which will reduce the production cost for long-term.

Figure 32 Concept Scute

7.3.2Mockup

After that, those two concepts need to have ergonomic test by using mockup.
Same underwear and subjects are used, but material changed to paperboard. The paperboard has the similar thickness and weight to the expectation module thickness from company. Easy to cut and shape is another advantage for using paperboard compared with foam used before.

7.3.2.1 Bridge Concept

There are two widths of modules are chose in this test, first is 3.5cm, second is 4cm. [Figure 33] the reason why chose two different size is because the wide the modules are, the more forces will be absorb, but less room for torso bending. So 3.5cm is the lower width limit, and 4cm is the upper limit.

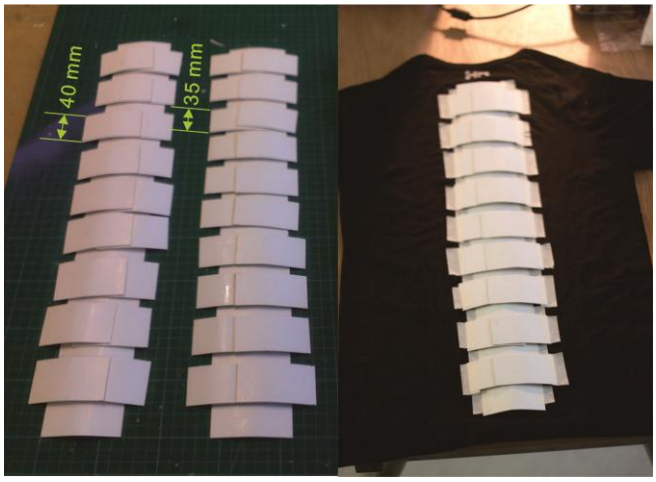


Figure 33 bridge concept mockup, 2 sizes

However the sizes different was not differ the result. From the opinion from the test subject, there is no obvious restrain feeling of the back protection during his movement. However, from the picture, both of the models have problems during torso lateral bending. The modules are conflicted with each other, and the situation was even worse with the unpredictable expansion of the fabric, some of them are lost the three bridges structure [Figure34]. It may have better performance with stronger glue or other joint methods are applied, but still the length of the modules needs to cut down to avoid the confliction. However, from the safety aspect, the length of modules is not available to become smaller enough to fulfill the new requirement. Therefore, in a conclusion, if the concept has to be continuously developed, more reasonable individual module shape and better joint solution needs to be explored. At the same time, the balance between safety and non-restrain requirement will be the main task during the new solution exploring process.

Figure 34 bridge concept mockup movement test

7.3.2.2 Scute concept

There are also two different sizes of modules are chosen to make mockup. First is with 7cm diameter another is 9cm [Figure35].same as concept 3, the 7cm is the lower

limits that can make the entire protective surface area fully covered the spine area of largest M size underwear. On another hand, 9cm is the upper limit for avoiding the protection from disturbing the scapula movement. The large the individual module is, the more area the protection will cover, which means more secure it will be. On the contrary, the bigger the modules are, the less comfort it may bring, and the restrain caused by confliction between them may also become a problem. That is why two size of modules need to be tested.

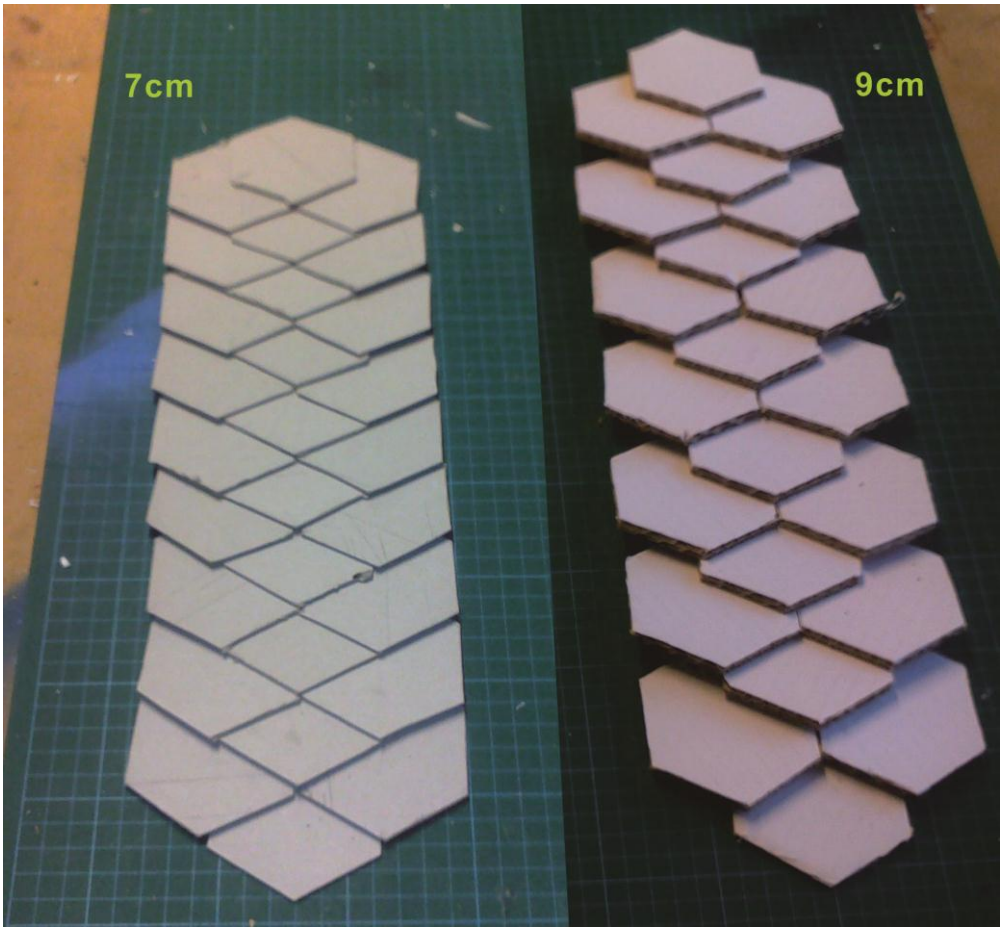


Figure 35 Scute mock up, 2 sizes

As it mentioned before, the hexagon shape is a material efficiency shape. From the cutting pattern from the paperboard [Figure 36], only little waste pieces are left.

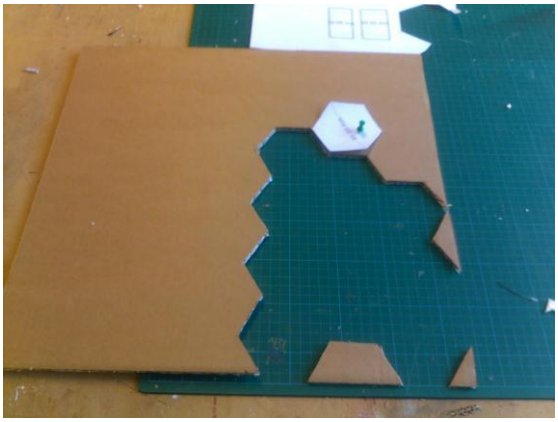


Figure 36 cutting pattern from the paperboard (scute concept)

The result [Figure 37] has good ergonomic performance as predicted. There are no restrain feelings for bending, twisting and lateral bending.

Figure 37 scute concept mockup movement test

7.3.3 Conclusion

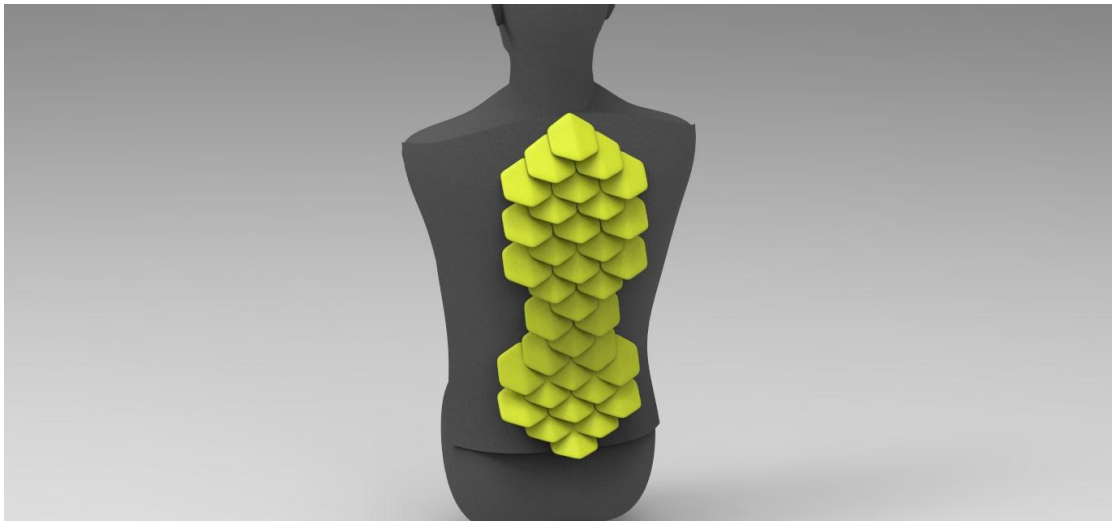
These two concepts are both reasonable extension of snake scales concept. Concept 3 successfully separated from fish scale feeling, but kept the structure and function as well. When the subject was wearing it on, it have satisfactory ergonomic performance during torso bending, and no complain of restrain feeling came out. However, from the observer perspective, concept 3 lost its protective structure during the lateral bending, which is consider as a fatal flaw from safety aspect. It means that changes should be made in module shapes based on precise calculation, which is an inappropriate direction to go deeper for this project. On the other hand, Scute concept had fewer changes than concept3 from original scales model, but transfer the sporty information to the users. In addition, it has perfect performance in ergonomic test, no matter from subject or observer's perspective, which shows a great potential to develop it as a successful concept. For the further concept development phase, few possible tracks could be, for example, more accurate and detailed shape and size of individual module, complete the structure to avoid turn-up, which are the suitable directions to go further for this project.

7.4 Concept Development Step2

After communication with company and client, both of them agree with choosing the Scute concept to continue with the concept development process. According to the plan, more detail need to be added to complete the result.

7.4.1 Scute concept-1

Scute concept-1 has more smoothed edges and chamfers on individual module, in order to eliminate the stress when the corner hit the ground. The bridge or arch shape again being used to add the structural strength of each module and the permeability of the whole protection.



7.4.2 Scute concept-2

The differences between scute-2 and scute-1 are the still in module shape. The new shape can fit the spaces between the modules much better than before. It also make the protection looks much thinner from lateral view.

Beside those two concepts, a reticular fabric can be used to cover the whole protection in order to avoid the modules turn-up problems.

7.4.3 Conclusion

These two newly developed concepts are successful examples for further concept development of this type of back protection. It will not be further developed in this thesis work because the company changed their goal for the second time as mentioned above. It end as only some concepts because strictly speaking, all the details added on module shapes, needs using mechanical calculation to optimization the design.

However, for this project, mechanical calculation is beyond the scope of the research from time and resource limitation. Those two concept developed here is used as an inspiration material to indicate an appropriate track for those who will interest in and will continue work with this project.

7.5 Material discussion

As it is mentioned before, the material selection is another key fact to the protection as ergonomic issues. Therefore, if following the normal material selection process, the workload will be equal to three or four individual Master Thesis work. Based on current situation, two consultations with experts from Department of Materials and Manufacturing Technology in Chalmers university of Technology was arranged.

7.5.1 Material Selection Context

In order to help the material experts to initiate the material selection process, the context of material selection need to be first defined by the designer, the company and the client.
First, the requirements from product development are listed below.

- Absorb or resist 5000N of impact down to certain level(845N)400-500N
- As thin as possible, 5mm-6mm or less for each module
- Less than 400g in total, 10g each module, as light as possible
- Washable, breathable material will be preferable
- no hazardous and toxic substances
- recyclable (environmental friendly)
- Easy to dye or with attractive color could be considered
- Material can have nice surface finish
- Target cost for the protection is 10-20 USD. 0.4-0.5USD per modules; Massive production requires.
- Could be two or three layers material combination
- Temperature requires from -45 degrees centigrade to 60 degrees centigrade

Secondly, for geometry, 8cm hexagon shape was first chose as the geometry of individual modules to simplify the material selection process. Thirdly, for massive production requires, injection molding will be a suitable choice for manufacturing the individual modules. The last but not least, joining method still a trick question for this stage, sewing or gluing are chosen to be the first two temporary choices.

7.5.2 Material suggestion

After define the context of material selection, several suggestions were given based on their experience.
The idea material should have several key properties. For example, first, high impact strength, because high impact strength means the material can absorb certain shock. Secondly, intermediate compressive strength, which means the material will not be too strong or too soft either. The last is low compressive modulus, so the material will deform relatively easily.
After narrow down the material property, several materials that he recommends to the application:

1. Polydimethylsiloxane (silicon rubber, trade name silopren): absorbs a lot of shock, same properties in a wide temperature range, good chemical resistance (problem thermoset=hard to recycle)
2. Natural rubber: Still the most commonly used rubber, low cost (25 SEK/kg), good impact properties and a good tear resistance (problem thermoset=hard to recycle).
3. EPDM (trade names: Nordel, Vistalon) even cheaper than natural rubber, low density, good impact properties and water resistance. (problem thermoset=hard to recycle).
4. Polyurethane (trade name: Sorbothane) it is claimed to absorb shock even better than silicon runner and natural rubber. (Health problems with polyurethane, also a thermoset).
5. SBS (trade names: Eastron, Kraton) thermoplastic elastomer with good impact properties, used in footwear, also relatively cheap 15 SEK/kg.

7.5.3 Conclusion

Among these materials listed above, the SBS consider as a best choice, because beyond all the similar properties to other choices, it is also 100 percent recyclable. Although, all the suggestion is based on individual's experience, but more choices will comes out with the help of long period precise material selection process.
The material list is not only show that there are certain scope of materials can be related with the final concept, but also proves that the concept have potential to be a real product if the process keeps going forward.

8 Evaluation Phase

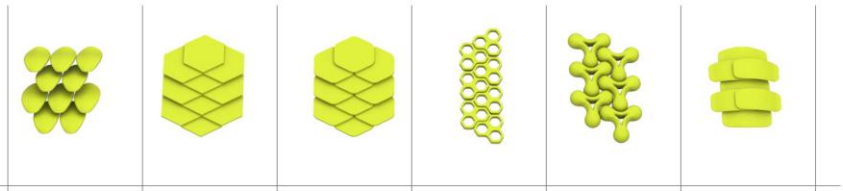
Because the sudden strategy shift comes from the company, which is using the ski pant instead of the underwear to combine with the back protection, the development of sports underwear back protection project was halt by the client. However, they believe that is too early to abandon any possible concepts from this thesis work in this stage of product development process even the goal was slightly changed, and they still consider the results from this thesis are valuable for their future research and development on ski pants or other project. That is why an evaluation was made for all of the concepts have been generated instead of proceeding with one current underwear back protection concept into a final design concept. The evaluation process was divided into 2 steps, first was appearance evaluation, and second was general evaluation. In addition, the comparison between different concepts is from aspect like, appearance of the protection, restrain to movement, permeability, potential to expand, puncture resistance and impact resistance. Those aspects are chose from the requirement list made by the client.

8.1 Appearance evaluation

The appearance evaluation pre done before the general evaluation is because the perception of form is very depending on the esthetics of individual. However, due to the structure is still unpatented, only small group of interviewees (6 people) participated in the survey. Because no core value have been decided yet, so the words chosen to make appearance assessment is according to the interview result, and expecting messages the founder try to deliver to the consumers. Therefore, secure, lightweight, sporty, innovative were the four words chosen to make the survey. Each participate need to use a score from 1 to 5, to grade how much extent the structure convey the feeling that each word stands for to him or her. The result was showed in

figure 38, and the total score is added by average score in each blank.

Appearance Evaluation



Secure	4.2	4.2	4	2.3	3.1	3.8
Light-weight	3.8	4.6	4.6	4.8	2.7	3.9
Sporty	3.7	4.6	4.2	4.8	3.8	1.8
Innovative	4.3	4.5	4.5	4.8	4.6	3.1
Total	16	17	17.3	16.7	14.2	12.6

Score from 1 to 5
1 no feeling at all
2 not obvious
3 little
4 adequate
5 strong expression

Figure 38 appearance evaluation result

As can be seen from the table, the Scute concept and its variation have the highest mark, scales and triangular honey cone have the second highest mark. Then, the "air ball" concept was following behind. The "bridge" concept got the last place. The first four concepts have relatively close score. When looking into each sub-term, the holes among "triangular honey cone" concept may lead to the most insecure structure but lightest feeling, and the bridge concept was considered to be the least sporty concept.

8.2 General evaluation

As can be seen from figure 39, each of the concepts has their own advantage and disadvantage. Scute concept-1 as a variation of Scute concept has the same scores as Scute concept, which are the most balance concepts among six. The original snake scale concept only defeated by Scute concept from appearance aspect. However, this evaluation from this aspect is depending too much on individual taste, which need further investigate from boarder interviewee pool. The honey cone concept and its variation "triangle air ball" concept also got similar score. As it mentioned before, this structure have fatal flaws on puncture resistance. However, since the ski pants have much less extendibility than underwear, this concept will still have potential to be further developed. The "bridge" concept has limited expansibility, because it can only cover spine area. Regardless of that, it still good enough to be a spine protection due

to its adequate score on other aspect. In a conclusion, although some of the concepts not fit for the underwear back protection use, but it may have great potential to be attached on other models. Furthermore, the Scute concept still the most balance model the wide application area for back protection design.

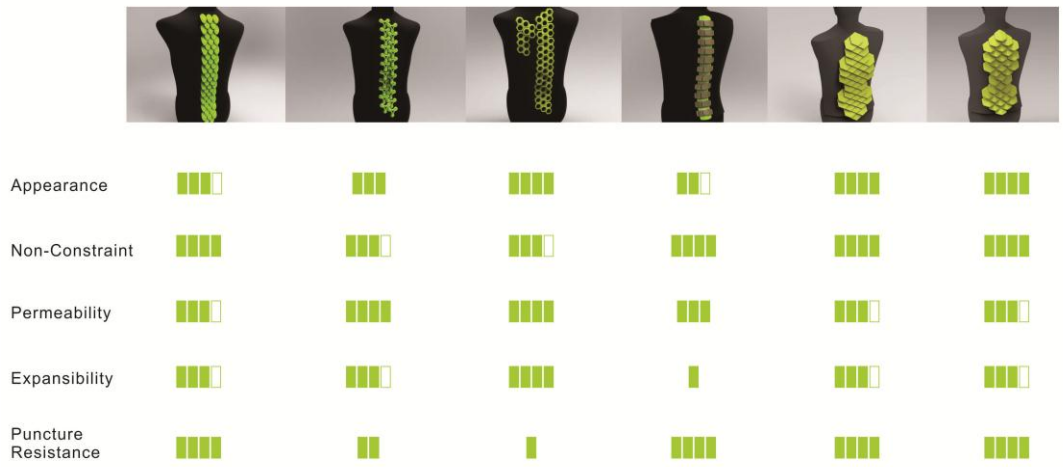


Figure 39 General evaluation results

8.3 Impact Test

Impact test for the back protection is a decisive phase, which will decide the whole thesis work success or not.
The equipment be chose according to European standard EN1621-2
Material used in this experiment is list in table 3

Names	Explanation
Dyneema	DSM Dyneema: SB51
Sorbathane	Sorbothane: 120106A 70 Duro Black 0,10” Thick, 111220A 0,20” thick
3D-lite	Camp AB, Runlite SA: 3D-lite

Table 3 Material Details

There are following subjects been tested during this experiment.

1. Dyneema 3 mm + Dyneema 0,2 mm + Sorbothane 3mm, rectangle 100 x 200 mm.
2. Dyneema 3 mm + Dyneema 0,2 mm + Sorbothane 6 mm, rectangle 100 x 200 mm.
3. Dyneema 3 mm + Dyneema 0,2 mm + Sorbothane 6 mm + Sorbothane 3 mm, rectangle 100 x 200 mm.
4. 3D lite 2 mm + Dyneema 0,2 mm + Sorbothane 6 mm + Sorbothane 6 mm, rectangle 100 x 200 mm.
5. Dyneema hex 3 mm + Dyneema 0,2 mm + Sorbothane 6 mm + Sorbothane 6 mm, rectangle 100 x 200 mm. arranged according to “Scales concept”

6. 3D-lite hex 2 mm + Sorbothane 3 mm + Dyneema 0,2 mm + Sorbothane 3 mm + Sorbothane 6 mm, rectangle 100 x 200 mm, arranged according to “Scales concept”

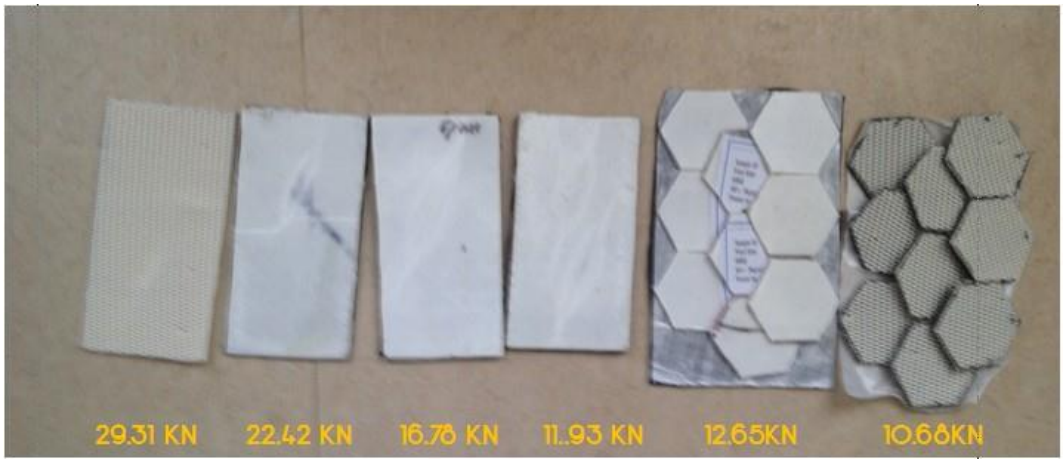


Figure 40 Impact Test Result

The result of test shows in figure 40. None of the example has pass the level 2 standard, which is the average peak force shall below 9kN and no single value shall exceed 12kN. (BSI Group, 2003). However, example number 8, which is using the arrangement of “scales concept” have dramatically decrease the impact to 10.48 KN, which is the closest one to pass the level 2. Although none of the example passes the EN1621-2, but it shows that the “Scales concept” successfully point out a way to find out the final solution, which is through the further exploration on individual module structure and material combination and innovation. By doing that, an idea model will be found to pass the standard EN1621-2.

9 Discussion

9.1 Method Discussion

Method discussion is about a conclusion for those methods played important roles in this master thesis. It is also a reference and suggestion for all designers who will use those methods in similar situation.

9.1.1 Interview, Questionnaire, Observation

The potential user group interview has made a large contribution to first stage of the research and concept development stage. It helped the designer understood the sports, the injury, and the demand on the back protection. During market analysis, some of the information was provided by the store own from interview. This information helped the designer experience more about the back protection product in the market than just read the product manuals.
On the other hand, questionnaire was always used together with interview process, but also use isolated when face-to-face interview was difficult to be arranged. It save times and document the answer in an efficient way.
Observation is also a method used together with interview. The recap of certain scene gave the designer a better understanding of the content described by the interviewees. The video shot from professional training room is excellent material for study the big picture of the body movement. However, this method is limited when used on complex or unapparent movement pattern, for example, back movement pattern.

9.1.2 Motion capture

Motion capture experiment is a break through point of the whole project. Without it, one can only complement by using imprecise observation or repeatedly mockup methods to gather the data, which is obviously neither accurate nor time saving.
It provides detailed information about back movement pattern. Some unexpected founding somehow changes the whole idea generation process. Beyond the contribution made to the idea generation stage, it also plays an important role in CAD modeling. The output data are not only compatible to data analysis software, but also to animation, video editing and modeling software. Because of that, it will provide wide range of data transfer and further application for back protection research.
However, at that time, the motion capture system in Human Science Faculty of Design, Kyushu University is a relatively old product from Motion Analysis

Company. Recently, there are more advanced cameras and specially designed spine movement sensors were delivered to the laboratory. It may dramatically improve the result if it was applied in this master thesis work. Anyway, the result from current experiment is adequate for this stage of the product development process.

9.1.3 Bionics

Using Bionics to inspire the idea generation process is another breakthrough of this master thesis work. For this thesis, it is a simple and clever solution to find a structure from the natural to protect a creation belongs to it. Human spine is a delicate structure, which have all 6-direction freedom movement. Normal artificial structure cannot follow the movement very well, no mention to be scalable. Using the fish or snake scales model has solved the challenges on structure. However, the scale model should not be applied mechanically to the back protection usage. The ergonomic fitting and exterior expression would be the next challenges. As can be seen from the previous chapter, visual appearance and other detailed issues were improved from original scales model. Still, there is a long way to go to make this concept to be a mature product, Bionics together with structural and material mechanics as well as methods from design and ergonomic aspect will transfer the "gift from nature" to a gift for skiers.

9.1.4 Mockup

Mockup is a traditional but not old-fashion method used for ergonomic assessment in design process. It plays a vital part of the whole design process, because it provide a simple and quick way to test and try on the concepts that developed only based on experimental data and computer aid modeling. Even if the data is fully detailed, the mockup process still consider as indispensable, because by performing mockup, many unexpected problem occurred, which would never be founded only by analyzing data. Besides, the paper mockup for explore the structure is also a useful tools. It transfers complex space imagination to simple and intuitive practical shape exploration.
Since this Master thesis is performed by only one developer, which makes the mockup procedure much difficult than 2 or more participate. It is because that the mockup test are constantly performed alongside with the concept development process, it is difficult to find a volunteer to follow the process as the developer does. Therefore, most of the tests are done on the same subject–the developer himself, which will lead to unnoticed deviation and error. In order to avoid this situation, 2 or more participate are strongly recommended for mockup test.

9.2 General Discussion

In general, the master thesis has reached the requirement from the client, and has positive contribution for their further research and other related product development. Still, there are some supplementary questions need to be point out and discussed, for example, the influence of the 3 times goal changes, the potential development track of current concept, and sustainable aspect.

9.2.1 Goal changes

Through the whole project, the requirement from client or company has changed for three times. From the beginning, the founder have the idea of develop a lightweight, thin and breathable back protection for skiing or general using, which is different from the products on the market. This goal consider as a start point of this master thesis, which affect the pre study, market research, and the first round of idea generation part.

As time went by, some investors have participated in, and they have interest in combine the protection with their sports underwear. Following from that, the goal was also slightly changed but much clearer than before. It must be emphasized that this goal became the main theme of the Master thesis. The works have done before the goal changes can still be used after compared the specific requirement changes, and the previous ongoing idea generation process has cancelled and restarted because of it. As can be seen from chapters before, there are several concepts are generated according to the new goal.

At the final stage of the thesis work, the investor suddenly changed their strategy due to some reason, and decided to use ski pants instead of underwear for attaching the back protection. The changes this time only affect the final result of this thesis work, because prototype making is no longer necessary. A concept evaluation replaces the prototype making for represent more usable information for the development of ski pants model.

The changes of goals have both positive and negative effects on the project. From the positive aspect, these changes are common and need to be faced as a designer in commercial product development process, because the unpredictable market needs will lead to sudden tactics changes. To quickly adapt into a vary situation is a skill that a product designer should have. When look back into the whole project, the result is successfully solve the questions and fulfill the requirements from the beginning to the end. Although the result designed for underwear model is not completely meet the needs for ski pants, but the concept generated from the project is valuable for further development. From the negative aspect, the changes of goal lead to redundant works and extra workload. The schedule planed in the beginning have disrupted by restart of

the idea generation process. Besides, the final result supposed to be carry out several prototype with presenting 1 or 2 different ideas. Since ski pants model taken place of the underwear model, there is no needs for produce the prototype at this stage, which leads to an unfinished product development process for underwear model.
In a conclusion, although the goal changes during the thesis work have some negative affect on the product development process, but in general the client is satisfied with result, which they consider as valuable to further research or on the other project.

9.2.2 Further Development

As it mentioned above, the goal changes leave the product development process unfinished, so desired future development possibilities will be discussed as follow.
For the underwear back protection, the Scute concept was strongly recommended, because it was designed for attaching on a stretch and flexible material. Another thing need to be noticed is that, the "Scute" is only stay in concept stage, the structure need to be promoted with the help from mechanical engineering aspect. Besides, material selection and appearance details are considered as equal important as the structure. Therefore, there are works including structural mechanics calculations, individual module shapes exploring, ventilation test, impact test, and branding are recommended for continuing design the underwear back protection.

For ski pants, snake scales can still fit the new requirement, but the honey cone concept and bridge concept will be good choices as well, because they took less surface area, and especially fit for the less stretch material. The Honey cone concept is foldable, which is another advantage for the ski pants concept. However, when the ski pants becomes to the host of the back protection, which is very different with underwear concept, more research needs to be done for finding an appropriate structure, not just using the current result carried out from this master thesis.

When look back from the beginning, it is risky to isolate the structure exploration to material research. Because of the limit knowledge and time of the author, too much workload forces him only to focus on structure exploration track. For afterward research, two or more developer from different area will be a better choice for this topic.

9.2.3 Sustainability Aspect

Sustainability aspect is always been kept in mind for the whole design process. In the material selection stage, an environmental friendly or recyclable material will be the first choices than those materials with even better fitted other parameters.

Moreover, the using of method bionic emphasis the importance of protection environment and maintain species diversity.as DaVinci said that ‘in her inventions nothing is lacking and nothing is superfluous’. The nature is wonderful creator, who provides us countless inspirations on areas like, design, energy, material, and medical, etc. As an individual, to keep her from pollution, global warming, etc. is an inescapable responsibility.

10 Conclusions

For underwear model, the final result, especially the Scute concept, have not only solve the problem for attaching on the stretchable material, but also meet the requirement from the client, which is lightweight, no movement restraint and good ventilation. Although the concept will no longer develop in this stage, but in the near future, it will be carried out again, and continue with more details study, like structure and material mechanics, branding, visualization, and production, etc.

For ski pants model, several concepts draw from underwear model still suitable for it. However, new research from the beginning is strongly recommended, because after all, the requirement and context are different.

The result of the thesis work received positive feedback from Physical Illusion AB and G-spine. They are planning to continue project in the near future.

The development process is generally good. The mutual understanding and trust between the author and client is crucial. The constantly communication and feedback keep the process go in a right track. The time spend on this thesis is unexpectedly longer than the planning, because the experiment in Japan, and 3 times goal changes. All the research and ideas were carried out by the only author, which may have flaws or better solutions in some steps. The result would become better if more time or specialists are involved.

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Appendices

Appendix A Potential user interview and questionnaire

Appendix A

1.1 Market interviews

Interviewee A, Storeowner

Store size, small

1. Questions about back protection

Does it only protect your back, spine? What about shoulder? Coccyx

It depends on type, the one for motorcycle are normally fully protected. For snow sports, normally spine (fully or partial) and shoulder are covered.

Does the "Size opinion" can fulfill all consumers' physical requirement? Does anyone of them complain it not suit him even it is the right "size" for him?

Yes. No.

Is there any special "sell point" on this protector? Is there any pros and cons

Like POC, it using special material, which can be bended on one direction but tough on another. But they are heavy than normal.

Is there any specific notes that consumer need to remember when he using it?

Find the right size, maybe.

Do you know what material it used?

PU, and PVC, some of them using their own special material.

Is there any other products that you suggest to buy together with the "back P" when a consumer comes to your shop? Or it is a suggestion when they buy helmet or other protectors? Why?

They normally come to buy other products like goggles and helmet, then I suggest them to try back protection.

2. Questions about Consumer

According to your selling experience, are there many people buy back protector? Compared with helmet?

It is hard to say, it is not the ski season right now, but during the winter it is quite welcomed.

I have heard a saying that one can only think about buying a back protector after he or she hurt their back. Is that true?

No, some of them bought it in the very beginning, as I know.

What do they think of the protector? Did you hear any complain about it when you sell it?

I don't know, it must be useful. No

Interviewee B, Store assistant

Store size, medium

1. Questions about back protection

Does it only protect your back, spine? What about shoulder? Coccyx

This type is only for motorcyclist, it covers whole body, shoulder, arm,etc.

Does the "Size opinion" can fulfill all consumers' physical requirement? Does anyone of them complain it not suit him even it is the right "size" for him?

Yes. No.

Is there any special "sell point" on this protector? Is there any pros and cons

For example, the FOX, It is compatible with the neck protection. And the back protection can be tear down, due to different usage. Of course, it is much more expensive than others.

Is there any specific notes that consumer need to remember when he using it?

The protection can not 100% prevent the injures, one must keep that in mind.

Do you know what material it used?

You can look into the introduction

Is there any other products that you suggest to buy together with the "back P" when a consumer comes to your shop? Or it is a suggestion when they buy helmet or other protectors? Why?

As I said before, the neck protection, it is their new product, sells quite good. Gloves, everything here in the store.

2. Questions about Consumer

According to your selling experience, are there many people buy back protector? Compared with helmet?

The "FOX" always sells good, the simple vision of this one, with reasonable price also a popular one.

I have heard a saying that one can only think about buying a back protector after he or she hurt their back. Is that true?

Motor cycle is a dangers sport, most of them using back protection.

What do they think of the protector? Did you hear any complain about it when you sell it?

Useful and necessary. Sometimes they complain too warm to wear.

Interviewee C, Store manager

Store size, large

1. Questions about back protection

Does it only protect your back, spine? What about shoulder? Coccyx

There are different types for different needs and function. Some of them are fully covered.

Does the "Size opinion" can fulfill all consumers' physical requirement? Does anyone of them complain it not suit him even it is the right "size" for him?

Yes, but most of band lack of female size.

Is there any special "sell point" on this protector? Is there any pros and cons

There is a soft material protection are already sold out right now, it is light weight, no restrain to the movement.

Is there any specific notes that consumer need to remember when he using it?

It must be tightly worn. If it moves it won't be function.

Do you know what material it used?

The soft material Scott using is called "d3o". the one that POC using is called VPD

Is there any other products that you suggest to buy together with the "back P" when a consumer comes to your shop? Or it is a suggestion when they buy helmet or other protectors? Why?

There are a lot, it depends on the consumers' need. Helmet and goggles are always mentioned.

2. Questions about Consumer

According to your selling experience, are there many people buy back protector? Compared with helmet?

There is lots of people buying back protection these days, they pay much more attention to it than before.

I have heard a saying that one can only think about buying a back protector after he or she hurt their back. Is that true?

That is true, people sometime don't aware the danger when it actually happened. But still many people are well prepared before they go to ski.

What do they think of the protector? Did you hear any complain about it when you sell it?

It is necessary to wear. Some of them complain about the restrain feelings.

1.2 Potential user interviews

Interviewee 1, male, 27, student

1. Questions about sports

When and why did you choose this sport in the beginning?

Skiing, I started when I was very young, with my parents.

Where do you usually ski or snowboard? How is it like? Temperature, windy?

Vemdalen, for downhill ski. We go there during the spring, temperature is about -20 °c to 10 °c.

What about the speed when you ski? The average and the highest speed? How much height when doing aerial tricks?

We have roughly calculated the speed for downhill ski. It is about 70km/h. we don't do many aerial tricks, normally 1m height.

Is there any movement that you need to twist or bend your back? And how? (How much angle)

When you accelerate, turning.

Have you ever hurt yourself on the back, shoulder, coccyx, neck ?

No, I sometimes fall down, but I haven't got any injuries.

When you fall, which part of your body usually land first? How did you fall?

Lateral body maybe. You should cross your arm and rolling when you fall.

2. Questions about back protector

When you start to use the back protector? why?

I didn't have one, but I am about to. In the beginning, I thought it was unnecessary to use it, since I am getting better, I am considering to have one.

Are there any other protectors you wear?

Goggles and helmet

How important do you think about the Shape and graphic design?

Very important, although you can't see it during the sports, but we have a "after ski". At that time people can notice the protection if it looks cool.

Do you have any suggestion about the back protector design?

Have a reasonable price with nice graphic works and cool shape.

Interviewee 2, male, 26, student

1. Questions about sports

When and why did you choose this sport in the beginning?

Snowboarding, I started when I was 9 or 10.

Where do you usually ski or snowboard? How is it like? Temperature, windy?

Vemdalen, Trysil. We go there every year for 1 or 2 weeks, temperature is about -20 °c to 10 °c.

What about the speed when you ski? The average and the highest speed? How much height when doing aerial tricks?

I don't know exact numbers but very quick. About 1m high in general, but if you count the slope, sometimes it reaches 3m.

Is there any movement that you need to twist or bend your back? And how? (How much angle)

When you turning, do some aerial tricks.

Have you ever hurt yourself on the back, shoulder, coccyx, neck ?

Yes, once I hurt my scapula area during tumbling on the ground.

When you fall, which part of your body usually land first? How did you fall?

Hips, perhaps, or cross your arm when falling forwards

2. Questions about back protector

When you start to use the back protector? why?

Since I start this sport. I got it as a gift from my parents.

Are there any other protectors you wear?

Goggles and helmet

Is your protector removable? Did you ever remove some of them because of different needs?

No, I sometimes fold it to fit in my ski bag.

How do you think your back protector?

Fit(without any movement) 1(not) 2 3 4 5(perfect) 4

Restrain 1(a lot) 2 3 4 5(not at all) 5

Weight 1(heavy) 3(adequate) 5(not feel anything) 5

Perspiration (warm) 1(always want to take if off) 3 (warm but actable) 5(not feel anything) 3

Does it slip horizontally?

No, it slips with my body movement but in a good way, with less restrain.

Is the lining removable? Do you think it is necessary to wash the lining?

No, I have never washed it before. It seems not dirty.

How important do you think about the Shape and graphic design?

It is important when you try to but a new one.

Do you have any suggestion about the back protector design?

As I said before, make it foldable, or somehow fit in the ski bag.

Interviewee 3, male, 28, student

1. Questions about sports

When and why did you choose this sport in the beginning?

Skiing. I started since I was 12.

Where do you usually ski or snowboard? How is it like? Temperature, windy?

Vemdalen, Åre, Trysil. We go there every year for 2 to 3 weeks; temperature is about -25 °c to 5 °c.

What about the speed when you ski? The average and the highest speed? How much height when doing aerial tricks?

About 30km/h to 50km/h. no many aerial tricks in cross country skiing.

Is there any movement that you need to twist or bend your back? And how? (How much angle)

When you turning left and right, accelerate, etc.

Have you ever hurt yourself on the back, shoulder, coccyx, neck ?

No

When you fall, which part of your body usually land first? How did you fall?

Cross the arms and rolling.

2. Questions about back protector

When you start to use the back protector? why?

After one or two years after I learnt how to skiing. Because I start to know the danger.

Are there any other protectors you wear?

Goggles and helmet

Is your protector removable? Did you ever remove some of them because of different needs?

Yes, it can be tear down to two parts, but I have never divided them.

How do you think your back protector?

Fit(without any movement) 1(not) 2 3 4 5(perfect) 4

Restrain 1(a lot) 2 3 4 5(not at all) 4

Weight 1(heavy) 3(adequate) 5(not feel anything) 5

Perspiration (warm) 1(always want to take if off) 3 (warm but actable) 5(not feel anything) 3

Does it slip horizontally?

A little, but worse thing is it slips vertically, because I am too thin to wear it.

Is the lining removable? Do you think it is necessary to wash the lining?

No, I have never washed it before. It seems not dirty.

How important do you think about the Shape and graphic design?

Not that important, but it should not be ugly as well.

Do you have any suggestion about the back protector design?

Find out a way to stop it slip vertically, for example, add a lap strip.

Interviewee 4, female, 27, student

3. Questions about sports

When and why did you choose this sport in the beginning?

Snowboarding. it is fun, I started when I was 13 or 14.

Where do you usually ski or snowboard? How is it like? Temperature, windy?

Vemdalen,I go there with my friends and families every year; temperature is about -20 °c to 10 °c.

What about the speed when you ski? The average and the highest speed? How much height when doing aerial tricks?

It is hard to say. Very quick. The jump is about 1m height.

Is there any movement that you need to twist or bend your back? And how? (How much angle)

Beside the turning and jumping. When you wearing on your boots or sit on the lift, the protection will makes you feel uncomfortable.

Have you ever hurt yourself on the back, shoulder, coccyx, neck ?

No

When you fall, which part of your body usually land first? How did you fall?

Hips, Cross the arms and rolling.

4. Questions about back protector

When you start to use the back protector? why?

I got is as a birthday president few years ago. Otherwise I won't buy it by myself

Are there any other protectors you wear?

Goggles and helmet

Is your protector removable? Did you ever remove some of them because of different needs?

No, maybe, I' vent look through it.

How do you think your back protector?

Fit(without any movement) 1(not) 2 3 4 5(perfect) 4

Restrain 1(a lot) 2 3 4 5(not at all) 4

Weight 1(heavy) 3(adequate) 5(not feel anything) 4

Perspiration (warm) 1(always want to take if off) 3 (warm but actable) 5(not feel anything) 3

Does it slip horizontally?

Sometimes, it follows your movement. As I said when you sit on the lift, the protection will move upwards and cause uncomfortable.

Is the lining removable? Do you think it is necessary to wash the lining?

No, I have never washed it before. It seems not dirty.

How important do you think about the Shape and graphic design?

Yes, very important, it is a gift to me, so it should be attractive as well.

Do you have any suggestion about the back protector design?

Find a way to solve the problem when you bend down wearing the boots and sitting on the lift. Maybe a special designed pattern for female users.

Interviewee 5, male, 27, student

5. Questions about sports

When and why did you choose this sport in the beginning?

Motorcycle. It is an exciting sport, I started it for like 3years ago.

Where do you usually ride? Temperature, windy?

I ride to school every day, sometimes on the highway.

What about the speed when you ski? The average and the highest speed? How much height when doing aerial tricks?

The highest speed is when I riding in the highway, it sometimes reach to 200km/h.

Is there any movement that you need to twist or bend your back? And how? (How much angle)

When turning, I need to turn left and right my necks to check the traffics.

Have you ever hurt yourself on the back, shoulder, coccyx, neck ?

I once fall in a ditch, and hurt my coccyx and buttock.

When you fall, which part of your body usually land first? How did you fall?

Shoulder, back or bottom. Because I always wear back protection.

6. Questions about back protector

When you start to use the back protector? why?

I bought it when I start this sport, because I know the dangerousness in the first place

Are there any other protectors you wear?

Helmet, protective leather suit for motorcyclist, gloves.

Is your protector removable? Did you ever remove some of them because of different needs?

No

How do you think your back protector?

Fit(without any movement) 1(not) 2 3 4 5(perfect) 4

Restrain 1(a lot) 2 3 4 5(not at all) 5

Weight 1(heavy) 3(adequate) 5(not feel anything) 5

Perspiration (warm) 1(always want to take if off) 3 (warm but actable) 5(not feel anything) 2

Does it slip horizontally?

No, I wear it inside the leather suit, it always tightly wrapped.

Is the lining removable? Do you think it is necessary to wash the lining?

No, I have never washed it before.

How important do you think about the Shape and graphic design?

Yes, as designer, but you have to admit that you can't see them for the most of time.

Do you have any suggestion about the back protector design?

The thin the better, better ventilation.

1.3 professional sports man questionnaire

Interviewee 1 Gender: Male Age 32

Height (cm) 189 Weight (kg) 73

Questions about sports

Which kind of ski you usually do (Multiple choice)

Cross country ski X

downhill ski/alpine ski X

military ski

ski-jumping

What's the temperature like when you doing the sports mentioned above?

Below -20 ℃ X

-20 ℃ to 0 ℃ X

0 ℃ to 20 ℃ X

Above 20 ℃

How often do you play?

1 or 2 weeks in a year

More than a month

Every months when weather allowed

Professional sportsman X

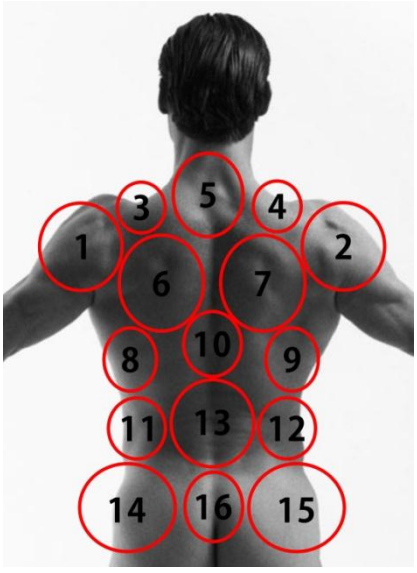
How long time do you usually spend on it per day?

1 hour

2 hours X

More than 3 hours

Have you hurt yourself on the back or trunk? (Not just injuries, but also painful and friction coursed by unpredictable landing) write down the numbers corresponding to the picture below.



Yes, I broke my shoulder (7) and have problem with back (13) after a compression.

Nei Alsdri slått og skadet rygg eller nakke.

Are there any other sports you do on the list below? (Multiple choice)
On land ski X
Off road bicycle X
Bicycle racing X
Skateboard
Other sports that may cause you fall down and hurt your back.

In general, if you can control, which part of your body will you try to land first when you fall down (Multiple choice)
Bottom
Shoulder
Hands X
Lateral of the body
back

Questions about back protector
Do you use back protector when you skiing or cycling? NO
If **YES**: A
Why do you bought it?
Got it as a gift
I considered ski is a dangerous sports in the first place
I have had hurt my back during ski before bought it
I had previews injuries on my back
It is attached promotional merchandise with other equipment I meant to buy.
I saw somebody else using it and it looks cool and useful
What do you think of your protector?
1) Fit(without any movement) 1(not) 2 3 4 5(perfect)
2) Weight 1(heavy) 3(adequate) 5(not feel anything)
3) Perspiration (warm) 1(always want to take if off) 3 (warm but actable) 5(not feel anything)
4) Is there any moment you feel it restrain your movement?
put on the boots and other equipment
sit on the ski lift
twist your trunk (turning left or right)
accelerate
head movement
others

If **NO**, why?
Never heard of such thing
Too expensive for me

I seldom do any dangerous movement X
I not always do these sports
It seems too retrain to my body movement
It seems too warm to wear X
Not fit for my helmet or goggles
There are no right size for me
I just start this sports, maybe I will try it 1 or 2 years later
I am an expert, and never fall down
Others

How much money you would like to spend on buying a new one (in Swedish kronor)
500-1000 1000-1500 X 1500-2000 2000+

Besides the comfort of the back protector, is the graphic design and shape also important to you when you try to buy a new one? 4
1 not at all 2 3 4 5 very important

Are there any other protectors you wear?
Helmet X
Goggle X
Neck protector
Shoulder protector
Chest protector

which kind of cycling you always do
Racing X
In door train
Off road X

Interviewee 2 Gender: female

Age: 22

Height 158,5cm

Weight 56,5kg

Questions about sports

Which kind of ski you usually do (Multiple choice)

Cross country ski

downhill ski/alpine ski

military ski

ski-jumping

What's the temperature like when you doing the sports mentioned above?

Below -20 ℃

-20 ℃ to 0 ℃

0 ℃ to 20 ℃

Above 20 ℃

How often do you play?

1 or 2 weeks in a year

More than a month

Every months when weather allowed

Professional sportsman

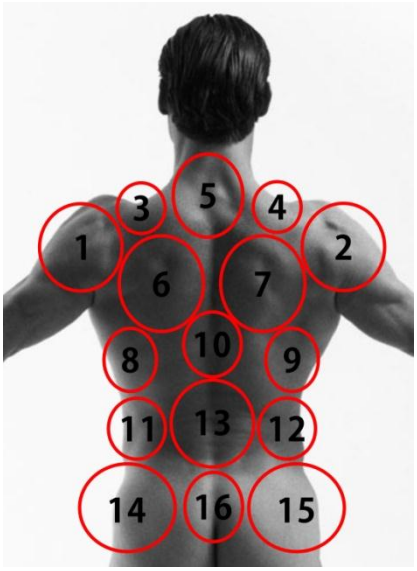
How long time do you usually spend on it per day?

1 hour

2 hours

More than 3 hours

Have you hurt yourself on the back or trunk? (Not just injuries, but also painful and friction coursed by unpredictable landing) write down the numbers corresponding to the picture below.



Yes, I broke my shoulder (7) and have problem with back (13) after a compression.

Are there any other sports you do on the list below? (Multiple choice)

On land ski

Off road bicycle

Bicycle racing

Skateboard

Other sports that may cause you fall down and hurt your back. Rulleski/rulleskøyter

In general, if you can control, which part of your body will you try to land first when you fall down (Multiple choice)

Bottom

Shoulder

Hands

Lateral of the body

back

Questions about back protector

Do you use back protector when you skiing or cycling?

If **YES**: A

Why do you bought it?

Got it as a gift

I considered ski is a dangerous sports in the first place

I have had hurt my back during ski before bought it

I had previews injuries on my back

It is attached promotional merchandise with other equipment I meant to buy.

I saw somebody else using it and it looks cool and useful

What do you think of your protector?

1) Fit(without any movement) 1(not) 2 3 4 5(perfect)

2) Weight 1(heavy) 3(adequate) 5(not feel anything)

3) Perspiration (warm) 1(always want to take if off) 3 (warm but actable) 5(not feel anything)

4) Is there any moment you feel it restrain your movement?

put on the boots and other equipment

sit on the ski lift

twist your trunk (turning left or right)

accelerate

head movement

others

If **NO**, why?

Never heard of such thing

Too expensive for me

I seldom do any dangerous movement

I not always do these sports

It seems too retrain to my body movement

It seems too warm to wear

Not fit for my helmet or goggles

There are no right size for me

I just start this sports, maybe I will try it 1 or 2 years later

I am an expert, and never fall down

Others

How much money you would like to spend on buying a new one (in Swedish kronor)

500-1000 1000-1500 1500-2000 2000+

Besides the comfort of the back protector, is the graphic design and shape also important to you when you try to buy a new one?

1 not at all 2 3 4 5 very important

Are there any other protectors you wear?

Helmet

Goggle

Neck protector

Shoulder protector

Chest protector

Interviewee 3 Gender: Female

Age 19

Height (cm) 170

Weight (kg) 61

Questions about sports

Which kind of ski you usually do (Multiple choice)

Cross country ski

downhill ski/alpine ski x

military ski

ski-jumping

What's the temperature like when you doing the sports mentioned above?

Below -20°c x

-20°c to 0°c x

0°c to 20°c

Above 20°c

How often do you play?

1 or 2 weeks in a year

More than a month

Every months when weather allowed

Professional sportsman x

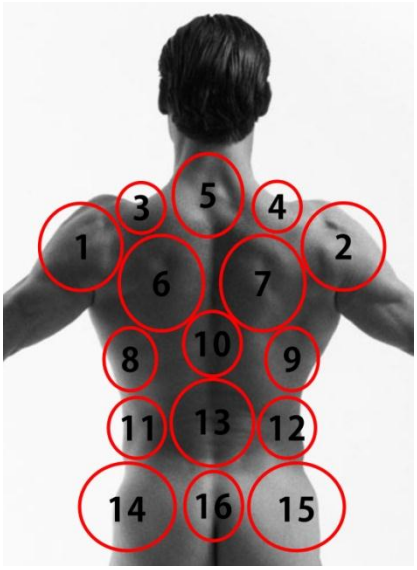
How long time do you usually spend on it per day?

1 hour

2 hours

More than 3 hours x

Have you hurt yourself on the back or trunk? (Not just injuries, but also painful and friction coursed by unpredictable landing) write down the numbers corresponding to the picture below.



Yes, I broke my shoulder (7) and have problem with back (13) after a compression.

Are there any other sports you do on the list below? (Multiple choice)

On land ski

Off road bicycle

Bicycle racing

Skateboard

Other sports that may cause you fall down and hurt your back.

In general, if you can control, which part of your body will you try to land first when you fall down (Multiple choice)

Bottom x

Shoulder

Hands

Lateral of the body

back

Questions about back protector

Do you use back protector when you skiing or cycling?

If **YES**: Yes

Why do you bought it?

Got it as a gift

I considered ski is a dangerous sports in the first place x

I have had hurt my back during ski before bought it

I had previews injuries on my back

It is attached promotional merchandise with other equipment I meant to buy.

I saw somebody else using it and it looks cool and useful

What do you think of your protector?

1) Fit(without any movement) 1(not) 2 3 4 5(perfect)

2) Weight 1(heavy) 3(adequate) 5(not feel anything)

3) Perspiration (warm) 1(always want to take if off) 3 (warm but actable) 5(not feel anything)

4) Is there any moment you feel it restrain your movement?

put on the boots and other equipment

sit on the ski lift

twist your trunk (turning left or right)

accelerate

head movement

others

If **NO**, why?

Never heard of such thing

Too expensive for me

I seldom do any dangerous movement

I not always do these sports

It seems too retrain to my body movement

It seems too warm to wear

Not fit for my helmet or goggles

There are no right size for me

I just start this sports, maybe I will try it 1 or 2 years later

I am an expert, and never fall down

Others

How much money you would like to spend on buying a new one (in Swedish kronor)

500-1000 x 1000-1500 x 1500-2000 2000+

Besides the comfort of the back protector, is the graphic design and shape also important to you when you try to buy a new one?

1 not at all 2 x 3 4 5 very important

Are there any other protectors you wear?

Helmet x

Goggle x

Neck protector

Shoulder protector

Chest protector

Interviewee 4 Gender: male

Age 18

Height (cm) 185

Weight (kg) 77

Questions about sports

Which kind of ski you usually do (Multiple choice)

Cross country ski

downhill ski/alpine ski

military ski

ski-jumping

What's the temperature like when you doing the sports mentioned above?

Below -20 ℃

-20 ℃ to 0 ℃

0 ℃ to 20 ℃

Above 20 ℃

How often do you play?

1 or 2 weeks in a year

More than a month

Every months when weather allowed

Professional sportsman

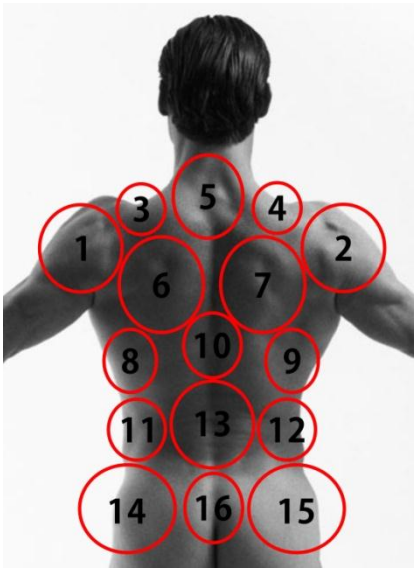
How long time do you usually spend on it per day?

1 hour

2 hours

More than 3 hours

Have you hurt yourself on the back or trunk? (Not just injuries, but also painful and friction coursed by unpredictable landing) write down the numbers corresponding to the picture below.



Yes, I hurt my back (6)(7)(10) a few times

Are there any other sports you do on the list below? (Multiple choice)

On land ski

Off road bicycle

Bicycle racing

Skateboard

Other sports that may cause you fall down and hurt your back.

In general, if you can control, which part of your body will you try to land first when you fall down (Multiple choice)

Bottom

Shoulder

Hands

Lateral of the body

back

Questions about back protector

Do you use back protector when you skiing or cycling?

If **YES**: A

Why do you bought it?

Got it as a gift

I considered ski is a dangerous sports in the first place

I have had hurt my back during ski before bought it

I had previews injuries on my back

It is attached promotional merchandise with other equipment I meant to buy.

I saw somebody else using it and it looks cool and useful

What do you think of your protector?

1) Fit(without any movement) 1(not) 2 3 4 5(perfect)

2) Weight 1(heavy) 3(adequate) 5(not feel anything)

3) Perspiration (warm) 1(always want to take if off) 3 (warm but actable) 5(not feel anything)

4) Is there any moment you feel it restrain your movement?

put on the boots and other equipment

sit on the ski lift

twist your trunk (turning left or right)

accelerate

head movement

others

If **NO**, why?

Never heard of such thing

Too expensive for me

I seldom do any dangerous movement
I not always do these sports
It seems too retrain to my body movement
It seems too warm to wear
Not fit for my helmet or goggles
There are no right size for me
I just start this sports, maybe I will try it 1 or 2 years later
I am an expert, and never fall down
Others

4. How much money you would like to spend on buying a new one (in Swedish kronor)
500-1000 1000-1500 1500-2000 2000+

5. Besides the comfort of the back protector, is the graphic design and shape also important to you when you try to buy a new one?
1 not at all 2 3 4 5 very important

6. Are there any other protectors you wear?
Helmet
Goggle
Neck protector
Shoulder protector
Chest protector

which kind of cycling you always do
Racing
In door train
Off road

Interviewee 5 Gender: female

Age : 27

Height (cm) : 173

Weight (kg) : 67

Questions about sports

Which kind of ski you usually do (Multiple choice)

Cross country ski

downhill ski/alpine ski - X

military ski

ski-jumping

What's the temperature like when you doing the sports mentioned above?

Below -20 ℃

-20 ℃ to 0 ℃ - X

0 ℃ to 20 ℃

Above 20 ℃

How often do you play?

1 or 2 weeks in a year

More than a month

Every months when weather allowed

Professional sportsman - X

How long time do you usually spend on it per day?

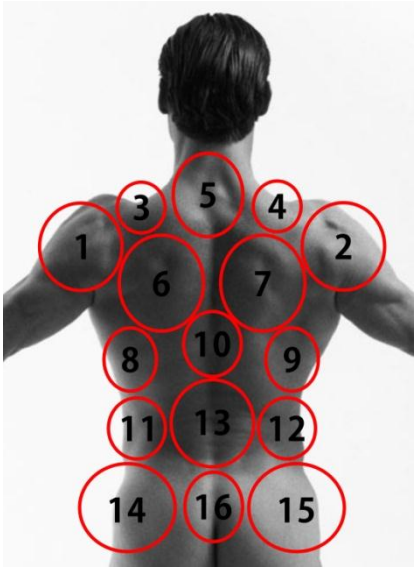
1 hour

2 hours

More than 3 hours - X

Have you hurt yourself on the back or trunk? (Not just injuries, but also painful and friction coursed by unpredictable landing) write down the numbers corresponding to the picture below.

NO.



Are there any other sports you do on the list below? (Multiple choice)
On land ski
Off road bicycle
Bicycle racing
Skateboard
Other sports that may cause you fall down and hurt your back.

In general, if you can control, which part of your body will you try to land first when you fall down (Multiple choice)
Bottom - X
Shoulder
Hands
Lateral of the body
back

Questions about back protector
Do you use back protector when you skiing or cycling? YES
If **YES**: A
Why do you bought it?
Got it as a gift - X
I considered ski is a dangerous sports in the first place
I have had hurt my back during ski before bought it
I had previews injuries on my back
It is attached promotional merchandise with other equipment I meant to buy.
I saw somebody else using it and it looks cool and useful
What do you think of your protector?
1) Fit(without any movement) 1(not) 2 3 4 5(perfect) - 3
2) Weight 1(heavy) 3(adequate) 5(not feel anything) - 2
3) Perspiration (warm) 1(always want to take if off) 3 (warm but actable) 5(not feel anything) - 1
4) Is there any moment you feel it restrain your movement?
put on the boots and other equipment
sit on the ski lift
twist your trunk (turning left or right)
accelerate
head movement
others – WHEN SKATING ON TELEMARKSKI

If **NO**, why?
Never heard of such thing

Too expensive for me
I seldom do any dangerous movement
I not always do these sports
It seems too retrain to my body movement
It seems too warm to wear
Not fit for my helmet or goggles
There are no right size for me
I just start this sports, maybe I will try it 1 or 2 years later
I am an expert, and never fall down
Others

How much money you would like to spend on buying a new one (in Swedish kronor)
500-1000 1000-1500 - X 1500-2000 2000+

Besides the comfort of the back protector, is the graphic design and shape also important to you when you try to buy a new one?
1 not at all 2 3 4 5 very important - 1

Are there any other protectors you wear?
Helmet - X
Goggle - X
Neck protector
Shoulder protector
Chest protector

Interviewee 6 Gender: Male

Age 28

Height (cm) 181

Weight (kg) 71

Questions about sports

Which kind of ski you usually do (Multiple choice)

Cross country ski

downhill ski/alpine ski

military ski

ski-jumping

What's the temperature like when you doing the sports mentioned above?

Below -20 ℃

-20 ℃ to 0 ℃

0 ℃ to 20 ℃

Above 20 ℃

How often do you play?

1 or 2 weeks in a year

More than a month

Every months when weather allowed

Professional sportsman

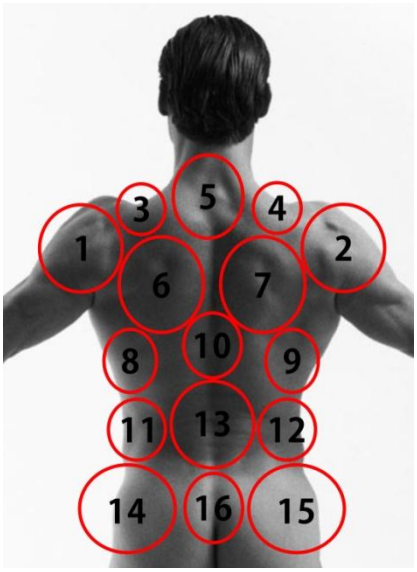
How long time do you usually spend on it per day?

1 hour

2 hours

More than 3 hours

Have you hurt yourself on the back or trunk? (Not just injuries, but also painful and friction coursed by unpredictable landing) write down the numbers corresponding to the picture below.



shoulder out of joint

Are there any other sports you do on the list below? (Multiple choice)

On land ski

Off road bicycle

Bicycle racing

Skateboard

Other sports that may cause you fall down and hurt your back.

In general, if you can control, which part of your body will you try to land first when you fall down (Multiple choice)

Bottom

Shoulder

Hands

Lateral of the body

back

Questions about back protector

Do you use back protector when you skiing or cycling?

If **YES**: A

Why do you bought it?

Got it as a gift

I considered ski is a dangerous sports in the first place

I have had hurt my back during ski before bought it

I had previews injuries on my back

It is attached promotional merchandise with other equipment I meant to buy.

I saw somebody else using it and it looks cool and useful

What do you think of your protector?

1) Fit(without any movement) 1(not) 2 3 4 5(perfect)

2) Weight 1(heavy) 3(adequate) 5(not feel anything)

3) Perspiration (warm) 1(always want to take if off) 3 (warm but actable) 5(not feel anything)

4) Is there any moment you feel it restrain your movement?

put on the boots and other equipment

sit on the ski lift

twist your trunk (turning left or right)

accelerate

head movement

others

If **NO**, why?

Never heard of such thing

Too expensive for me

I seldom do any dangerous movement
I not always do these sports
It seems too retrain to my body movement
It seems too warm to wear
Not fit for my helmet or goggles
There are no right size for me
I just start this sports, maybe I will try it 1 or 2 years later
I am an expert, and never fall down
Others

How much money you would like to spend on buying a new one (in Swedish kronor)
500-1000 1000-1500 1500-2000 2000+

Besides the comfort of the back protector, is the graphic design and shape also important to you when you try to buy a new one?
1 not at all 2 3 4 5 very important

Are there any other protectors you wear?
Helmet
Goggle
Neck protector
Shoulder protector
Chest protector

Interviewee 7

Gender: Female

Age 22

Height (cm) 169

Weight (kg) 76

Questions about sports

Which kind of ski you usually do (Multiple choice) Skicross – freestyle

Cross country ski

downhill ski/alpine ski

military ski

ski-jumping

What's the temperature like when you doing the sports mentioned above?

Below -20 ℃

-20 ℃ to 0 ℃

0 ℃ to 20 ℃

Above 20 ℃

How often do you play?

1 or 2 weeks in a year

More than a month

Every months when weather allowed

Professional sportsman

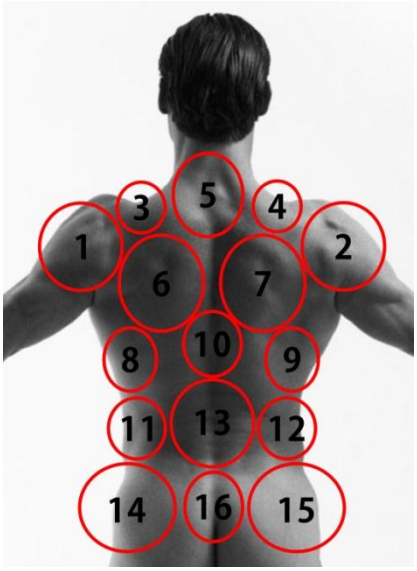
How long time do you usually spend on it per day?

1 hour

2 hours

More than 3 hours

Have you hurt yourself on the back or trunk? (Not just injuries, but also painful and friction coursed by unpredictable landing) write down the numbers corresponding to the picture below.



Yes, I have problems with my hip (14) after a compression/crash.

Are there any other sports you do on the list below? (Multiple choice)

On land ski

Off road bicycle

Bicycle racing

Skateboard

Other sports that may cause you fall down and hurt your back.

In general, if you can control, which part of your body will you try to land first when you fall down (Multiple choice)

Bottom

Shoulder

Hands

Lateral of the body

back

Questions about back protector

Do you use back protector when you skiing or cycling?

If **YES**: A

Why do you bought it?

Got it as a gift

I considered ski is a dangerous sports in the first place

I have had hurt my back during ski before bought it

I had previews injuries on my back

It is attached promotional merchandise with other equipment I meant to buy.

I saw somebody else using it and it looks cool and useful

What do you think of your protector?

1) Fit(without any movement) 1(not) 2 3 4 5(perfect)

2) Weight 1(heavy) 3(adequate) 5(not feel anything)

3) Perspiration (warm) 1(always want to take if off) 3 (warm but actable) 5(not feel anything)

4) Is there any moment you feel it restrain your movement?

put on the boots and other equipment

sit on the ski lift

twist your trunk (turning left or right)

accelerate

head movement

others

If **NO**, why?

Never heard of such thing
Too expensive for me
I seldom do any dangerous movement
I not always do these sports
It seems too retrain to my body movement
It seems too warm to wear
Not fit for my helmet or goggles
There are no right size for me
I just start this sports, maybe I will try it 1 or 2 years later
I am an expert, and never fall down
Others

4. How much money you would like to spend on buying a new one (in Swedish kronor)
500-1000 1000-1500 1500-2000 2000+

5. Besides the comfort of the back protector, is the graphic design and shape also important to you when you try to buy a new one?
1 not at all 2 3 4 5 very important

6. Are there any other protectors you wear?
Helmet
Goggle
Neck protector
Shoulder protector
Chest protector

which kind of cycling you always do
Racing
In door train
Off road