DESIGN OF ERGONOMIC PROTECTIVE GEAR TO IMPROVE PERFORMANCE IN IN-LINE SKATING

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Abstract

The use of protective equipment amongst inline skaters is dangerously low. This master thesis, addressing the redesign of skating knee pads, aims to study the reasons leading to this behaviour and the current knee pads in the market. With this information, a new design has been created.

Understanding that the main reasons for not wearing protective equipment when rollerblading are peer pressure, cost, lack of perceived need, discomfort, inconvenience and aesthetics, the project revolves around solving these issues.

The new knee pad is designed for competitive or professional skaters who are looking for a tool to improve their sport performance. It includes electronic components that offer biometric measurements which can be translated into performance data. Through Bluetooth communication, this information can be viewed by the user on an activity band, mobile phone or computer.

The design offers lighter solutions with excellent protective materials, combining them to create a luxury piece of equipment for elite skaters.

Keywords

Rollerblading, inline skating, knee pads, personal protective equipment, sports design, wearables

Abstract

El uso de protecciones entre patinadores sobre ruedas es peligrosamente bajo. Este trabajo de fin de máster, enfocado al rediseño de rodilleras de patinaje, tiene el objetivo de estudiar las razones que llevan a este comportamiento y las rodilleras que actualmente se encuentran en el mercado. Con esta información, un nuevo diseño ha sido creado.

Entendiendo que las principales razones para no utilizar protecciones al patinar son la presión de grupo, el coste, la falta de necesidad percibida, la incomodidad, la molestia y la estética, este proyecto se centra en resolver estos puntos.

La nueva rodillera está diseñada para patinadores competitivos o profesionales que están buscando una herramienta para mejorar su rendimiento deportivo. Incluye componentes electrónicos que ofrecen medidas biométricas que pueden ser traducidas a datos de rendimiento. A través de comunicación Bluetooth, esta información puede ser visualizada por el usuario mediante una pulsera de actividad, un dispositivo móvil o un ordenador.

El diseño ofrece una solución más ligera con excelentes materiales de protección, combinándolos para crear una pieza de equipamiento de lujo para patinadores de élite.

Palabras clave

Patinaje sobre ruedas, rodilleras, equipo de protección personal, diseño deportivo, wearables

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1

INTRODUCTION

1. Introduction

1.1. Introduction

Inline skating is an activity millions of people around the world engage in. Many of these skaters rarely wear protective equipment when wearing skates. It is necessary to raise awareness of the importance of this equipment, which includes a helmet, wrist guards, and knee and elbow pads (Jordan, Leddy, & Bisson, 2008), and foster its use by re-designing them. The topic of this research is the search for the reasons behind the lack of use of protective equipment in inline skating. These results will later be used to design knee pads which will improve the user's satisfaction and performance by offering a solution that will adapt to the different movements required by this sport, as well as incorporating electronic elements.

The choice of this topic was mostly personal, due to an interest in health topics and in the rollerblading world. I have been an inline skater for ten years and I have always been interested in the design of the protective equipment. Most existing protections are basic and uncomfortable, and there is a clear need amongst skaters to wear them more often, especially for those with more experience in inline skating.

1.2. Justification

With the increasing amount of rollerblading enthusiasts worldwide, injuries related to this sport have drastically increased. This has been directly linked to lack of personal protective equipment (PPE) use, which could reduce the frequency of injuries or at least reduce their seriousness (Morrongiello, Lasenby, & Walpole, 2007; Sherker & Cassell, 2001; Tan, Seldes, & Daluiski, 2001).

Sport injuries might discourage children and teenagers from participating in such activities, increasing the risk of health problems such as obesity (No Author, 2006). For this very reason, it is imperative that skaters use PPE to prevent injuries. Injury prevention strategies in inline skating have to be designed, focusing on promoting the use of PPE targeted to specific age groups and skating levels.

The most important piece of PPE is the helmet, although most skaters consider it to be the wrist guards. Helmet design is very restricted and has to follow rigid criteria, which is why this PPE was not chosen for the project. Wrist guards are the second most important piece of PPE due to the amount of registered injuries in wrists. When a person falls, the instinctive reaction is to position the arms in front of the body to protect it from the fall. Still, the implications of an injury on the wrist are lower than those on the knee. An injury on the lower limbs can prevent the user from rollerblading again (due to lack of confidence or to the injuries themselves), as well as hindering a normal daily life, away from rollerblading, by limiting the person's mobility. For these reasons, the chosen piece of PPE to study and improve was a knee pad.

Thus, the study of the underlying reasons for the lack of use of PPE in inline skating will help identify the user's needs, expectations and frustrations when it comes to these elements. This will create a solid basis for the re-design of knee pads, augmenting the use of PPE in skaters, reducing the chances of injuries (in the knee, in this case) and improving the user's state of health, amongst other benefits.

1.3. Objectives

After an initial and basic investigation on the subject to identify the problem, dissatisfaction with the current protective equipment in the rollerblading environment was found. Many users do not wear any of the protective elements when rollerblading, leading to an increase in injuries and hospitalisations.

With the increasing popularity of this sport, it is imperative that the design of protective equipment is rethought and translated into products that respond to the user's needs. The main objective of this master's thesis is to design a knee pad that responds to inline skaters' needs by being functional and aesthetically pleasing. Manufacturing has to be kept in mind, as well as the addition of electronic elements and the use of innovative materials for this type of product.

The final design should be environmentally friendly, with a brand design to identify the knee pads, as well as a price that should be as low as possible taking into account its added value with the use of innovative elements.

It would be interesting to develop a prototype at the end of the design phase to validate the concept and to correct undetected issues in the design. The best way to check whether the design is viable would be to have a user try this prototype.

1.4. Scope and methodology

For this project, a list of tasks to develop has been established. This organization method creates a set of requirements that have to be met and helps keep the goal visible, as well as easily detecting the tasks that still have to be developed.

INTRODUCTION	Justification of the chosen topic, the objectives of the project, its scope and methodology, and the time organization, presented as a Gantt diagram
REGULATIONS	Research on existing regulations regarding sports protective equipment to know the limitations of the design and apply these guidelines on the final product
RESEARCH PHASE	Bibliographic research to gain the existing knowledge to help design tests, questionnaire and interview with inline skaters to identify needs and expectations, anthropometric research to establish key measurements for the design and research of other relevant information for the project
ANALYSIS OF EXISTING PRODUCTS	Description of the general characteristics of knee pads, as well as the study of current commercialised products to identify strong and weak points in the design, and analysis of main manufacturers

PRE-CONCEPTUAL PROPOSAL	Define the brief of the project, including the basic requirements for the final design, including a description of the user, and the goals in functionality, aesthetics and electronics
DESIGN PROCESS	Use of design tools to present different solutions to the problem (S.C.A.M.P.E.R., visual and functional inconsistencies and brainstorming), as well as an initial electronic brainstorming
CONCEPTUAL DESIGN	Designing the final solution at a conceptual level, both in body and electronics, to further analyse the requirements of the design in the following stages
MATERIALS AND MANUFACTURING	Study of materials and manufacturing methods for the chosen design, and final choices, described in detail
FORMAL DESIGN	Product 2D drawings and renders to visualise the final proposal, as well as mechanical simulations to support the design choice; the design of the brand's visual identity can be found here
BUDGET	The costs of the complete project and the product
CONCLUSIONS	Results obtained in comparison to the initial objectives, as well as a critical review of the project and the possibilities of future projects based on this one
PROJECT LAYOUT	Design of the project's layout and presentation

1.5. Timeline

The timeline for this project is approximately 21 weeks, beginning from the moment the topic proposal was accepted. From that moment on, a Gantt diagram was created to keep track of the tasks that had to be developed and to see, at a glance, the state in which the project was at a certain time. It has had to be constantly updated with changes in the calendar or to reflect tasks that took a longer time to be completed.

	WEEKS																					
TASK	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
Introduction																						
Regulations																						
Research phase																						
Analysis of existing products																						
Pre-conceptual proposal																						
Design process																						
Conceptual design																						
Materials and manufacturing																						
Formal design																						
Budget																						
Conclusions																						
Layout																						

2

REGULATIONS

2. Regulations

There are a set of rules and regulations regarding protective equipment for sports, and inline skating associations have published rules for the usage of PPE in a competitive context. The regulations can be found in the annexes.

Regulation (EU) 2016/425 (European Parliament & Council of the European Union, 2016) states the health requirements that the PPE must pass, as well as other indications such as product marking to inform the user about the product itself.

EN 14120:2003+A1:2007 (AENOR, 2007) lists the mechanical properties of roller sports PPE and the test methods to validate them. It offers specific information for each piece of PPE.

The International Rules for Inline Freestyle (FIRS Freestyle Technical Commitee, 2017) state that it is not compulsory to wear any protective equipment, but strongly recommend using wrist guards. In speed skating, according to the Royal Spanish Skating Federation (Real Federación Española de Patinaje, 2017), protective equipment for joints may be worn, but it cannot have any rigid parts. In the general rules for roller sports, this Federation states that the compulsory protective equipment is a helmet, hand and wrist guards, elbow pads, knee pads and vertebrae protection when competing. In roller inline hockey, skaters must wear protective equipment at all times, with a soft protective covering of at least 12.5 mm thick, according to the International Federation of Roller Sports (International Federation of Roller Sports, 2010). Knee pads that cannot shift must be worn when competing in inline alpine track (World Skate Roller Alpine and Downhill Technical Committee, 2017).

3

RESEARCH PHASE

3. Research phase

3.1. Key concepts

For this investigation, it is important to establish the definition of the terminology used throughout the bibliography, as well as in other areas related to the subject of study.

The definition of personal protective equipment (PPE) refers to protective clothing, helmets, goggles, and other garments that are worn to protect an individual from injuries. Before PPE was used in the work environment, PPE was often used during wars (Cheung, 2013).

The equipment for sports on wheels is defined as "devices that can be subjected to each foot separately, or both at the same time, or which one can get on without subjection, which incorporate wheels of free spin and not motor driven." (AENOR, 2007). PPE in sports on wheels is a protection element against abrasions, bruises and fractures. It does not prevent all injuries (AENOR, 2007). In inline skating, the main risk for skaters is the impact against the floor or against (intentional or unintentional) obstacles which can cause physical injuries (AENOR, 2007). Inline skating protective equipment must protect the user from abrasions, bruises and fractures.

The difference between normal sports on wheels and acrobatic sports on wheels should also be explained, given that these two variants of the sport may lead to different user requirements. Normal sports on wheels are defined as the "use of sports on wheels equipment to move around without performing acrobatic manoeuvres" (AENOR, 2007), while acrobatic sports on wheels are the "use of sports on wheels equipment with natural or artificial obstacles to perform acrobatic manoeuvres" (AENOR, 2007).

Finally, knee protectors (also known as knee pads) are "devices which are worn on the knee, intended for the reduction of injury risk caused by impact or abrasion" (AENOR, 2007).

3.2. Historical evolution and patents

Protective equipment has been historically present throughout human history. In ancient times, soldiers wore protective equipment in battles, including head and face gear, as well as body armours, to defend themselves. This protective equipment was extremely heavy and uncomfortable to wear, but nevertheless, it was able to save many lives.

In a different setting, in the middle ages, blacksmiths wore protective gear (hand gear, aprons or shields) to protect their body against the high heat of the metal they worked with ('The History of Personal Protective Equipment', n.d.). More recently, other types of PPE are commonly used as protective work gear, such as protective shoes or coveralls in factories.

These elements have also been applied to the world of sports. The protection is adapted to the specific sport it will be used in, and covers different needs depending on the final use of the object. In the case of rollerblading, and specifically knee pads, there are many patents that can show the historical evolution of this piece of PPE. The following are a selection of these, including the ones most similar to this project.

In 1941, Robert H. Manzeck patented a flexible knee pad, protecting the most vital parts of the knee, for strenuous competitive sports. The goals of this design were to offer a comfortable solution that allowed for a large range of movement whilst protecting the user. Its parts were interchangeable and this helped repair and substitute parts very easily. It was very easy to place and affordable for most users (US2251362, 1941).

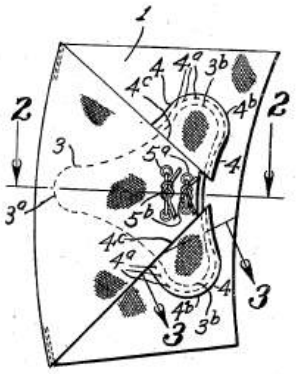
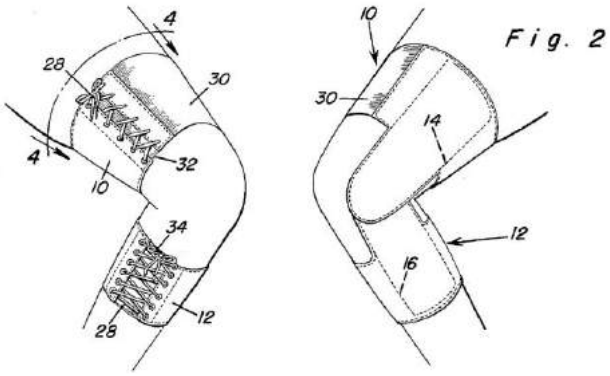


Illustration 1. Patent "Knee guard" (US2251362, 1941)

Years later, in 1956, a support for knee pads or braces was patented. The innovation in this product was the possibility of adding removable protective pieces, which allowed it to adapt to different shapes or sizes (US2746051, 1956).

Illustration 2. Patent "Elastic tongue insert for knee guard or brace" (US2746051, 1956)

The following relevant patent, from 1990 by Cheng-Shung Chang, is a protective pad, very similar to those we wear today. Its design is especially focused on sports uses, protecting the knee pad with a padded layer for the front side of the knee and elastic material on the back (US4914753, 1990).



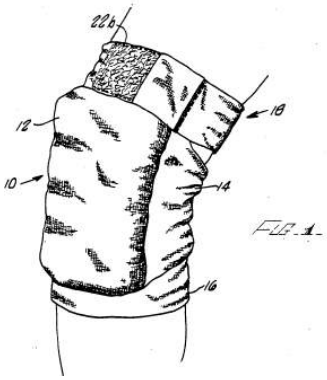
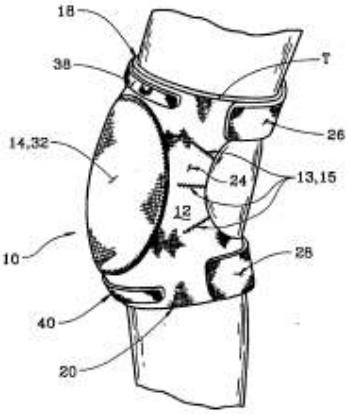


Illustration 3. Patent "Athletic knee pads" (US4914753, 1990)

In 1993, Norman D. Levine patented a knee pad for sports activities. It was make of a waterproof and elastic body, light and ergonomic. The back of the knee pad was open to allow for the leg to breathe (US005255391A, 1993).

Illustration 4. Patent "Knee pad" (US005255391A, 1993)



Another interesting patented design from two years later are the custom fit guards, in which the inner part of the knee pad can be adapted to the user's body for a better fit. Holding this material under hot water, the material becomes flexible and can take the shape of the user's leg if placed and held against it. Once it cools down, it keeps its new shape (US005405312A, 1995).

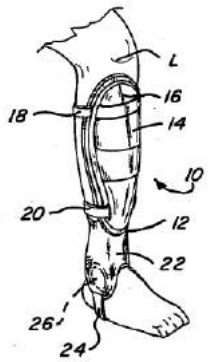
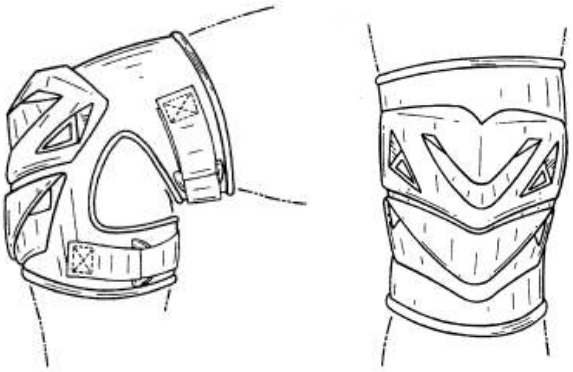


Illustration 5. Patent "Custom fit body guards" (US005405312A, 1995)

In 1996, Rollerblade, Inc. patented the aesthetics of a knee pad (US00D373655S, 1996), making the product seem very modern. It is important to note that Rollerblade is currently one of the largest rollerblading companies in the market.

Illustration 6. Patent "Knee guard" (US00D373655S, 1996)

Rollerblade, Inc. also patented, a few years later, a padded knee guard. The idea behind this design is the union between two pads by means of hinges. The opposite side is fastened with a stretchable fabric (US005727252A, 1998).



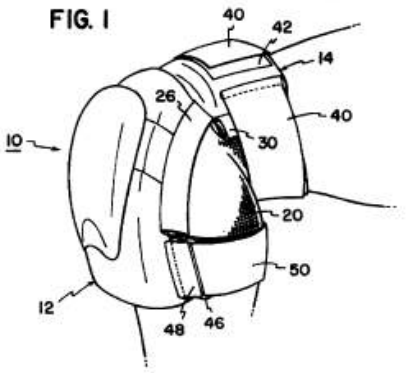
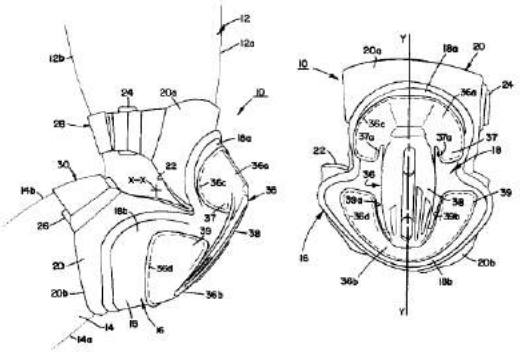


Illustration 7. Patent "Padded knee guard" (US005727252A, 1998)

Soon after, Rollerblade, Inc. also patented a design, useful for both knee and elbow pads, with fasteners on the top and bottom edges that allow the user to adjust the degree of attachment of the pad. The protective material is abrasion resistant and is divided into two parts to improve freedom of movement (US005915529A, 1999).

Illustration 8. Patent "Joint guard" (US005915529A, 1999)

As a novelty design, Cycle Express, Inc. patented in 1999 a joint protector with a design addressed to children. The protective material protects the joint, but it also has a playful and young feel. The thought behind this product was to promote the use of PPE amongst children (US005978962A, 1999).



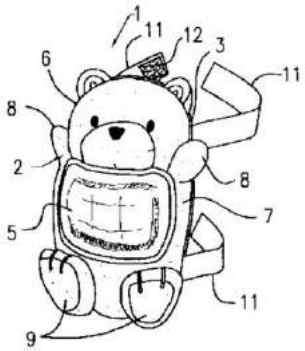
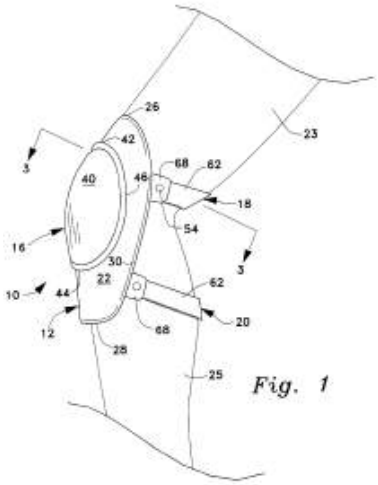


Illustration 9. Patent "Integrated knee or elbow protector and plush toy" (US005978962A, 1999)

A knee pad was patented in 2001 which offered a padding surface with a fluid-filled chamber attached to it. This block is removable and lets the user place different types of chambers (gas-filled, liquid-filled, gel-filled…) to adapt to different types of activities (US006253376B1, 2001).

Illustration 10. Patent "Knee pad" (US006253376B1, 2001)



That very same year, Bauer Nike Hockey Inc. patented an extensible leg pad, mainly designed for hockey players, consisting of a rigid portion to protect the knee and the shin, and a lower potion with a second shin shield. These shields overlap and allow for adjustment of the length of the pad to adapt to different user sizes or needs (US006272682B1, 2001)

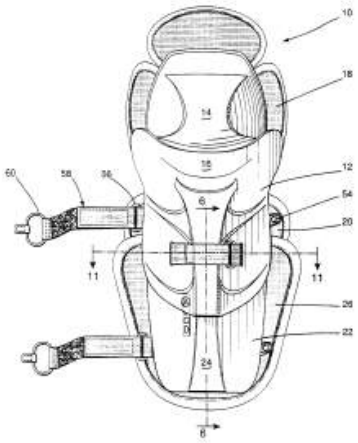
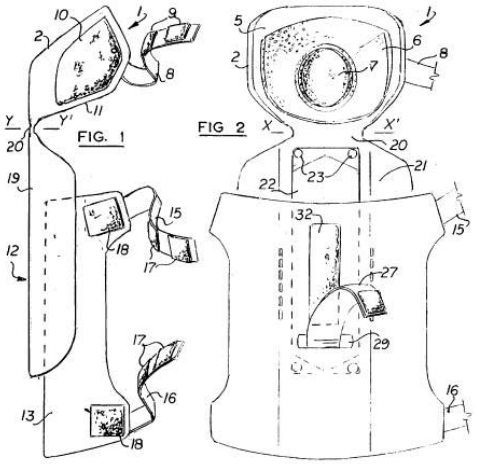


Illustration 11. Patent "Extensible leg pad" (US006272682B1, 2001)

The following patent not only protected the knee, but also the area above and below it by using two parts protecting each of the sections of the leg. It also protected a part of the shin, making it adaptable to a wider variety of sport applications (US006393610B1, 2002).

Illustration 12. Patent "Articulated knee and shin guard" (US006393610B1, 2002)



FLA Orthopedics, Inc. patented in the year 2002 a knee pad for industrial applications requiring kneeling. It is composed of a rigid layer, an inner cushion and a laminated fabric pad in contact with the user (US006401245B1, 2002).

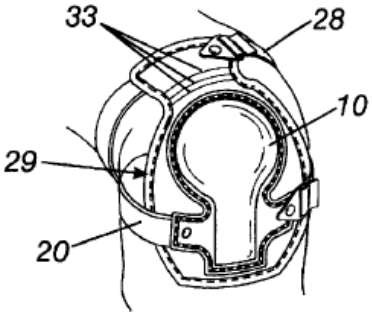
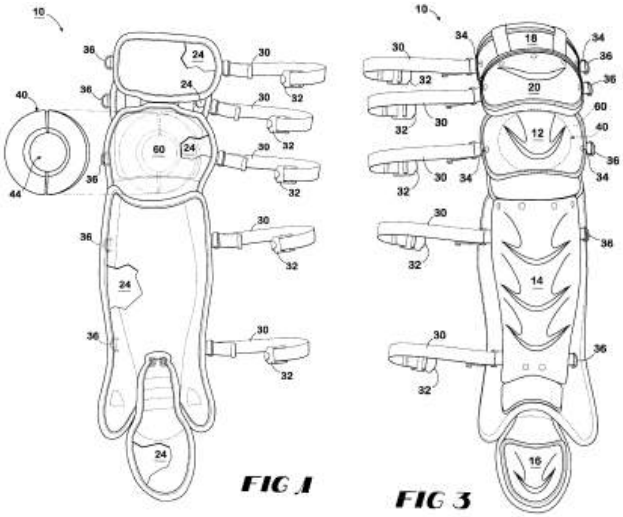


Illustration 13. Patent "Knee pad and manufacturing method" (US006401245B1, 2002)

Mizuno Corporation's 2003 patent consisted in a leg guard with a removable insert. One of the sections of this product is focused solely on protecting the knee (US006553572B2, 2003).

Illustration 14. Patent "Removable insert for athletic leg guards" (US006553572B2, 2003)

Another patent by Bauer Nike Hockey Inc. is an adjustable leg pad assembly. It includes a knee shield, a shin shield, a liner, a shield extension, an adjustable liner, and fasteners (US006654961B2, 2003).



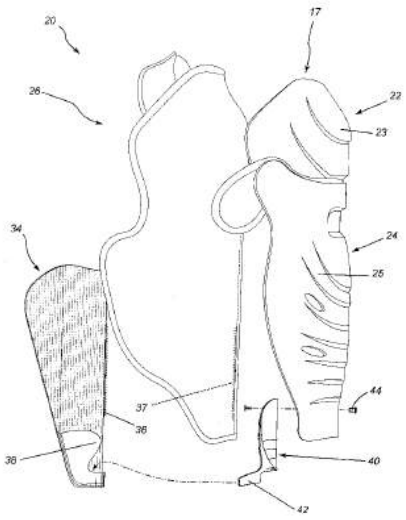
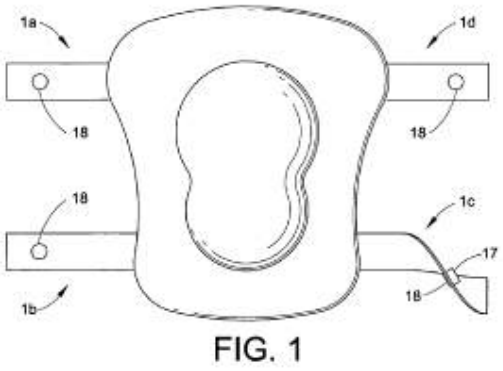


Illustration 15. Patent "Adjustable leg pad assembly" (US006654961B2, 2003)

In 2006, a knee pad was patented, which allowed the user to wear on top of trousers. Its design removed the straps, improving user movements (US006988281B1, 2006). Its application is mainly addressed to an industrial setting, but the principles of wearing a knee pad on top of clothes can be applied to sports equipment.

Illustration 16. Patent "Kneepad" (US006988281B1, 2006)



The following concept is interesting for its innovative design. It is a disposable and adhesive knee pad. Its design is focused on a work environment, and offers a temporary protection on the knee. It is attached to the user's trousers and does not cause any damage or leave any residue on the fabric (US007296301B1, 2007).

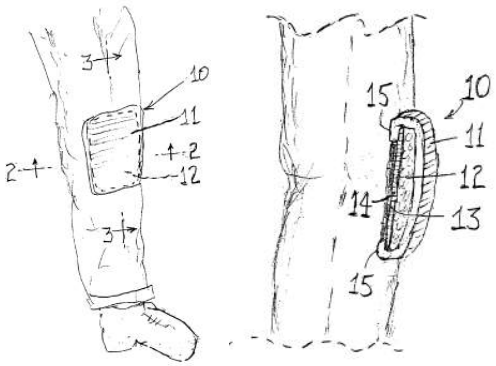


Illustration 17. Patent "Disposable detachable adhesive knee-pad" (US007296301B1, 2007)

The final patent in this section, from 2017, is a knee pad with a protective layer and an inner padded layer for comfort. Its design is once again focused on the work environment, but it is very similar to sports knee pads (ES634800T3, 2017).

3.3. Bibliographic research

This study aims to identify uses of PPE through different age groups and skating levels. It is also important to detect the underlying reasons for not using PPE and which elements are worn. The basic PPE consists of a helmet, wrist guards, and elbow and knee pads (Jordan et al., 2008). The differences in PPE use may lead to a variety of injuries with different seriousness levels. These are also studied.

The research is done through a bibliographic review of inline skating articles. Each of them have been chosen for their focus: use of PPE across age groups, reasons for PPE use, medical aspects of injuries and their relation to the PPE worn, and injury implications.

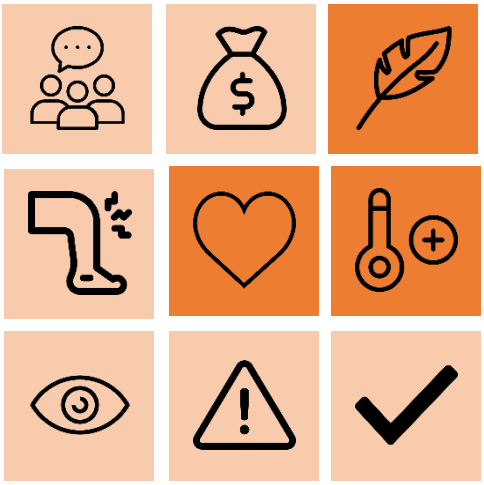
There are certain inconsistencies between studies due to research design problems or differences in observation samples. Still, most authors agree on the lack of PPE use. One of the studies observed that only 1.2% of skaters wore all the PPE, while 31.7% wore none. The rest wore one (39.7%), two (14.5%) or three (13%) pieces (Manning, 1995). Another observational study identified wrist guards as the most used piece of PPE (16.3%), followed by the helmet (12.2%) and knee (9.8%) and elbow pads (7.3%) (Warda et al., 1998). A more recent study found that as many as 66.7% of inline skaters wore no PPE and only 2.2% wore all of the equipment.

The most commonly used piece of PPE were wrist guards (25.9%) and knee pads (23.5%) (Sherker & Cassell, 2001).

Differences have been found across age groups, with children being more likely to wear a helmet than teens (12 to 19 years old), and adults being more likely to wear wrist guards than children. The use of PPE has been found to be more prominent amongst females, and the highest rates of PPE use can be found in children younger than 8 and in adults (Warda et al., 1998). Experienced skaters tend to wear more PPE than unexperienced users (Brudvik, 2006).

Inline skaters are more prone to fractures in their upper limbs (Brudvik, 2006; Rosenberg, 1994): distal radius, hand, elbow and clavicle (Jordan et al., 2008); and these injuries mainly affect males (71%) due to a lower PPE use. The most common inline injuries are minor, but can also be one of the following: minor abrasions and contusions, substantial fractures/dislocations, catastrophic head trauma and fatalities (Tan et al., 2001). The most frequently injured areas are the ankle and the knee, followed by upper body parts (Jordan et al., 2008). Amongst the injured skaters, 73% of them were experienced (43% of them having been wearing PPE at the time of the accident), while only 20% of the least experienced injured skaters wore PPE (Brudvik, 2006). Children younger than 20 had suffered 60% of the observed inline related injuries in comparison to older users (Warda et al., 1998), but one must keep in mind that nearly 1,500 injuries were observed in users 65 years and over, but are not considered as a risk group due to the small amount of inline skaters in this age group (Tan et al., 2001). Low experience has been associated to a higher fracture rate (Brudvik, 2006), while 63% of observed inline skaters did no stretching before their rollerblading session, with the possibility of developing chronic problems derived from unprepared skating, such as skating knee or muscle strains (Rosenberg, 1994).

Most observed inline skating injuries could have been prevented by the use of PPE, but could also be due to a lack of skill and risky behaviour (Connaughton & Barbello, 1999). Risk compensation was found amongst children and their parents. When using PPE, children engaged in more risk-taking and parents were more permissive, believing that PPE would fully protect them from injury. Although PPE may protect the user from inline skating injuries, they are not likely to protect from other types of injuries derived from a greater risk-taking (Morrongiello et al., 2007).



Reasons for not using PPE include peer pressure (Sherker & Cassell, 2001), cost of the protective equipment, discomfort, lack of perceived need, undesirable appearance and inconvenience in use (Tan et al., 2001; Warda et al., 1998). For this reason, PPE must be attractive and fashionable (Manning, 1995), using lightweight materials and designs that prevent overheating, as well as adapting correctly to different types of users (Rubin, 1998). Most prevention strategies should be targeted towards teenagers (Warda et al., 1998), and towards children aged 11 to 13 (Brudvik, 2006). Recommendations for safer inline skating include purchasing durable PPE, securely fitted when rollerblading, checking the state of the PPE to ensure it is safe to use, and avoiding rollerblading activities at night, wearing reflective clothing when there is insufficient light (Connaughton & Barbello, 1999).

Having identified the risk groups, preventive strategies can be designed targeting the different types of users. The results have shown that males tend to wear less PPE and participate in more

risk-taking activities, and therefore suffer more inline skating injuries than females. Adults tend to wear more PPE than children, leading to the conclusion that children should be taught the importance of PPE use. They should also be explained the danger of engaging in more risk-taking activities when wearing PPE and the limitations of these protections. Still, PPE use is extremely low in all age groups and inline skating levels, and should be redesigned to attract more users, as well as informing them of the benefits of wearing PPE.

Although the upper limbs suffer the majority of serious injuries, lower limbs are affected more frequently. Because lower limbs are more important for inline skating, it would be advisable to design better PPE for these areas. As studies have shown, this new PPE should be attractive and adaptable to users (and therefore targeted or customisable), light and comfortable.

3.4. Questionnaire

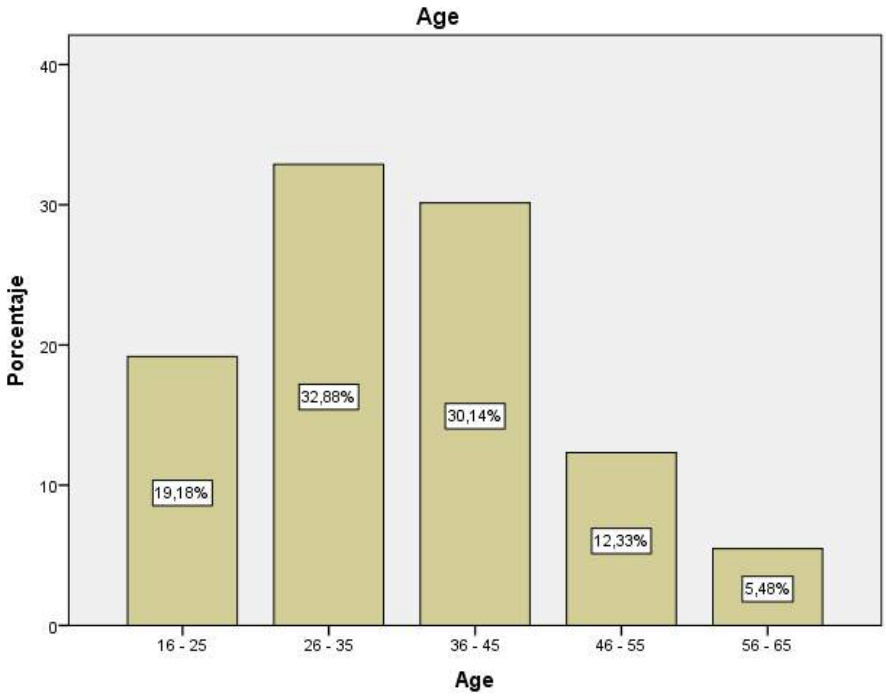
To understand the motivations, needs and expectations of the users, a questionnaire was designed. This questionnaire was created to be answered by skaters exclusively, although their level was considered unimportant when asking them to participate. It was answered by 73 people from different age groups, genders and rollerblading abilities and experience.

The questionnaire was divided in blocks to help establish the questions needed (see annexes) for a certain goal. The following table (Table 1. Questionnaire. Question blocks) lists each of the blocks and the objective of every one of them. The results were later analysed by using SPSS software.

Table 1. Questionnaire. Question blocks

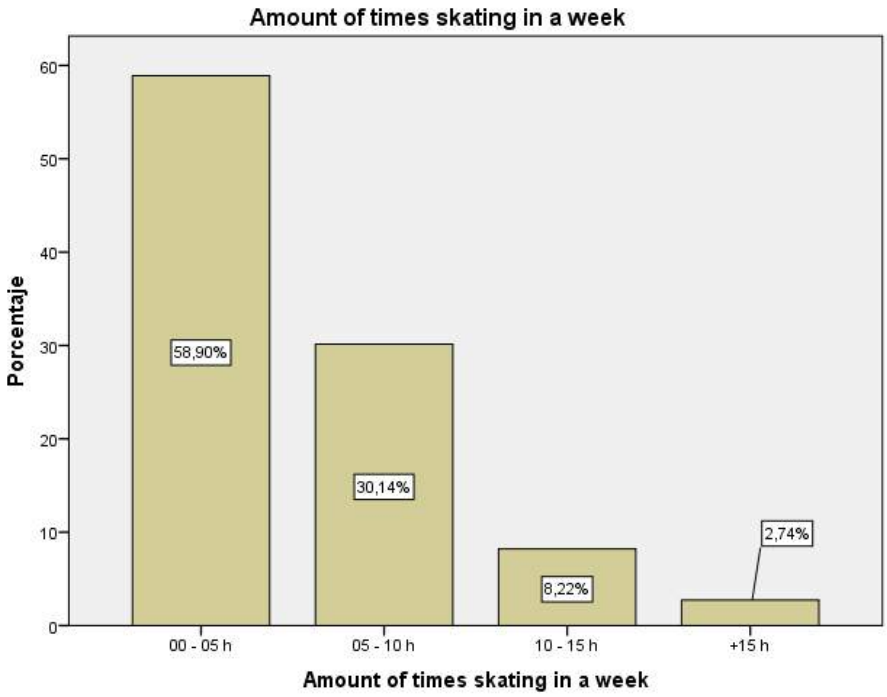
Block	Objective
About you	Questions about age and gender to have general information that might be linked to other questions
About rollerblading	Rollerblading habits and knowledge to identify the type of skater
Learning	To check if there is a link between learning methods and use of PPE
Use of protective equipment	Frequency and situations of PPE use, satisfaction regarding PPE and PPE maintenance
Opinion	Perceived need of PPE and general opinion on PPE use to detect design opportunities

As can be seen in the following graph (Graph 1. Questionnaire. Age), the respondent's age groups can be seen. These results only represent a small portion of the rollerblading community, but it is interesting to see that the most represented age groups are those between 16 and 45 years old. These age groups are approximately those linked to a typical rollerblading profile. Genders were also equally represented, with a 57.53% females and a 42.47% males.

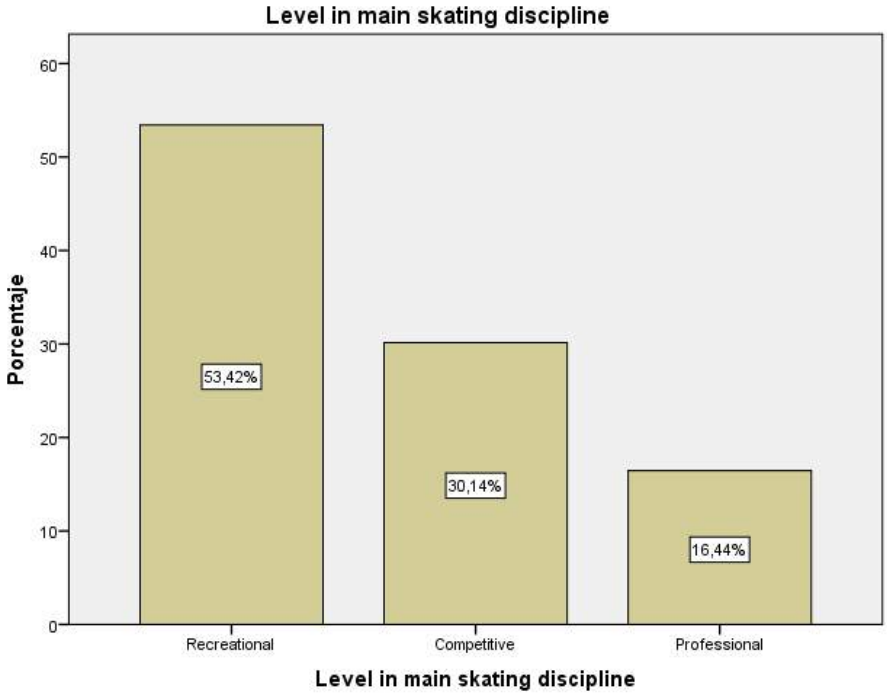


Graph 1. Questionnaire. Age

Amongst respondents, users typically train around 0 to 10 hours a week (Graph 2. Questionnaire. Amount of times skating in a week), which is consistent with the amount of professional skaters, representing 16.44% of the sample (Graph 3. Questionnaire. Level in main skating discipline). Still, experienced skaters from at least a competitive level represent 46.58%.



Graph 2. Questionnaire. Amount of times skating in a week



Graph 3. Questionnaire. Level in main skating discipline

In the following tables (Table 2. Questionnaire. Situations of use of PPE vs level in main skating discipline and Table 3. Questionnaire. Use of knee pads vs level in main skating discipline), the level in the main skating discipline has been compared with the habits of PPE use. In the first case (Table 2. Questionnaire. Situations of use of PPE vs level in main skating

discipline), there is not a significant difference between never using PPE and the level of skating. But in the case of the use of knee pads, its use decreases as the experience level increases. Professionals use the least knee pads (4.5%), which is an alarming rate of users (Table 3. Questionnaire. Use of knee pads vs level in main skating discipline).

Table 2. Questionnaire. Situations of use of PPE vs level in main skating discipline

Crossed table

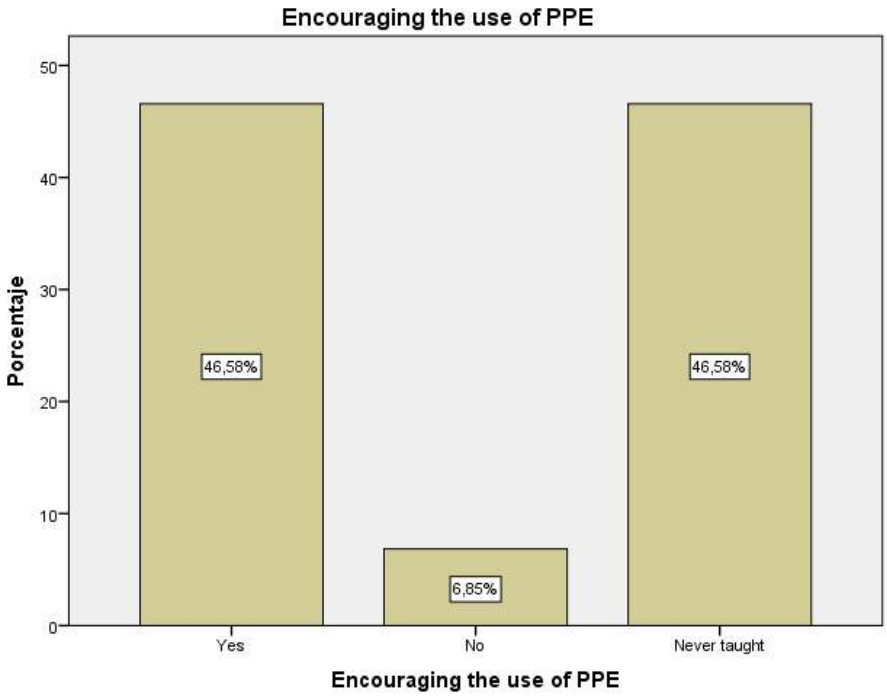
			Never
Level in main skating discipline	Recreational	Recount	5
		% within Never	35,7%
	Competitive	Recount	4
		% within Never	28,6%
	Professional	Recount	5
		% within Never	35,7%
Total		Recount	14
		% within Never	100,0%

Table 3. Questionnaire. Use of knee pads vs level in main skating discipline

Crossed table

			Knee pads use	Total
Level in main skating discipline	Recreational	Recount	28	28
		% within Knee pads	63,6%	63,6%
	Competitive	Recount	14	14
		% within Knee pads	31,8%	31,8%
	Professional	Recount	2	2
		% within Knee pads	4,5%	4,5%
Total		Recount	44	44
		% within Knee pads	100,0%	100,0%

Another interesting finding is that most skaters who have taught at some point will encourage the use of PPE, although they might not wear it themselves (Graph 4. Questionnaire. Encouraging the use of PPE).



Graph 4. Questionnaire. Encouraging the use of PPE

It is notable that skaters tend to use PPE most frequently when practicing their main modality (Table 4. Questionnaire. Situations of PPE use). This means that the design of PPE should be adapted to different skating disciplines rather than other activities on skates.

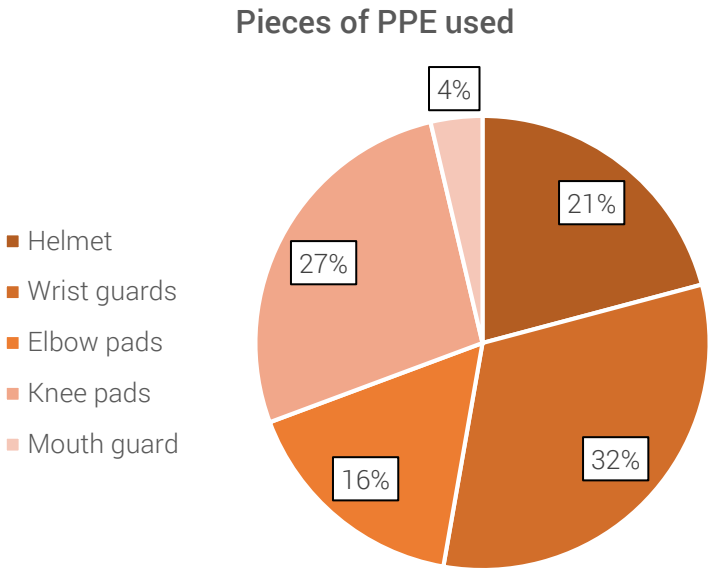
Table 4. Questionnaire. Situations of PPE use

D1 frequencies

		Answers		Percentage of cases
		N	Percentage	
Situations of PPE use[a]	Moving around	32	24,6%	43,8%
	In main discipline	39	30,0%	53,4%
	When teaching	26	20,0%	35,6%
	When doing exhibitions/competitions	19	14,6%	26,0%
	Never	14	10,8%	19,2%
Total		130	100,0%	178,1%

a. Dichotomy group tabulated at value 1.

Consistent with the bibliographic research, the most used pieces of PPE are wrist guards and elbow pads (Graph 5. Questionnaire. Pieces of PPE used), even though it has been stated that helmets are the most important piece of PPE. Knowing that knee pads are one of the most used pieces, it is important that its design corresponds with the user's needs, to encourage the use of PPE.

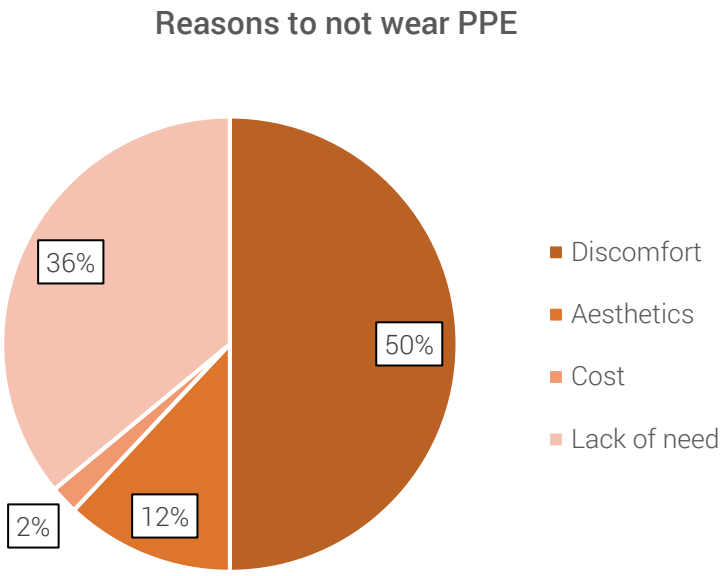


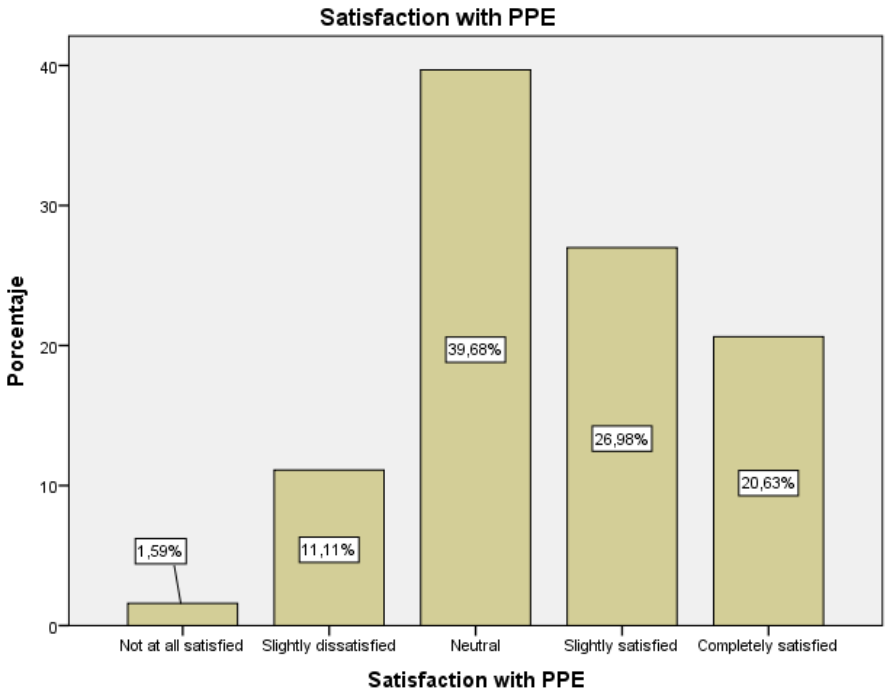
Graph 5. Questionnaire. Pieces of PPE used

The main reasons for not wearing PPE (Graph 6. Questionnaire. Reasons to not wear PPE) are mainly discomfort and a perceived lack of need. This also validates the results of the bibliographic research, in which these were two of the most important reasons.

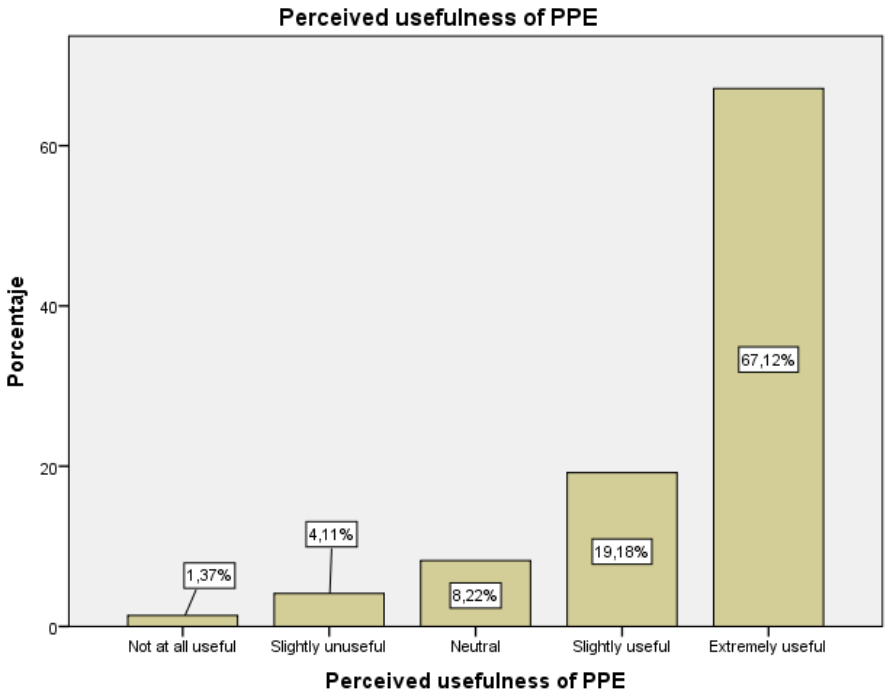
Graph 6. Questionnaire. Reasons to not wear PPE

The level of satisfaction with current PPE designs is mostly positive, although it is mainly neutral (Graph 7. Questionnaire. Satisfaction with PPE). It is also important to compare these results to the perceived usefulness of PPE pieces, which are surprisingly considered extremely useful (Graph 8. Questionnaire. Perceived usefulness of PPE). Still, many users wear no PPE.



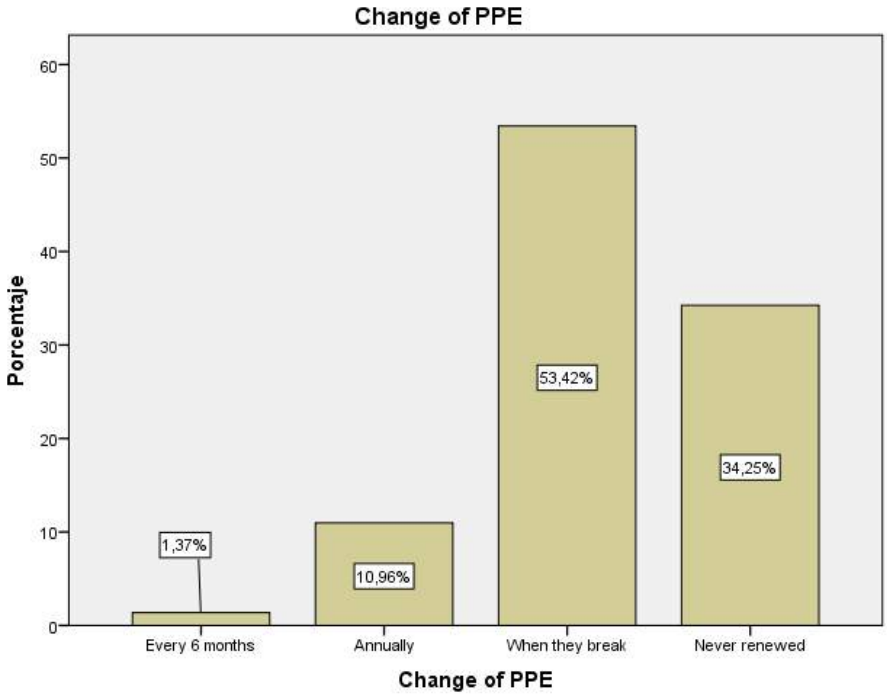


Graph 7. Questionnaire. Satisfaction with PPE



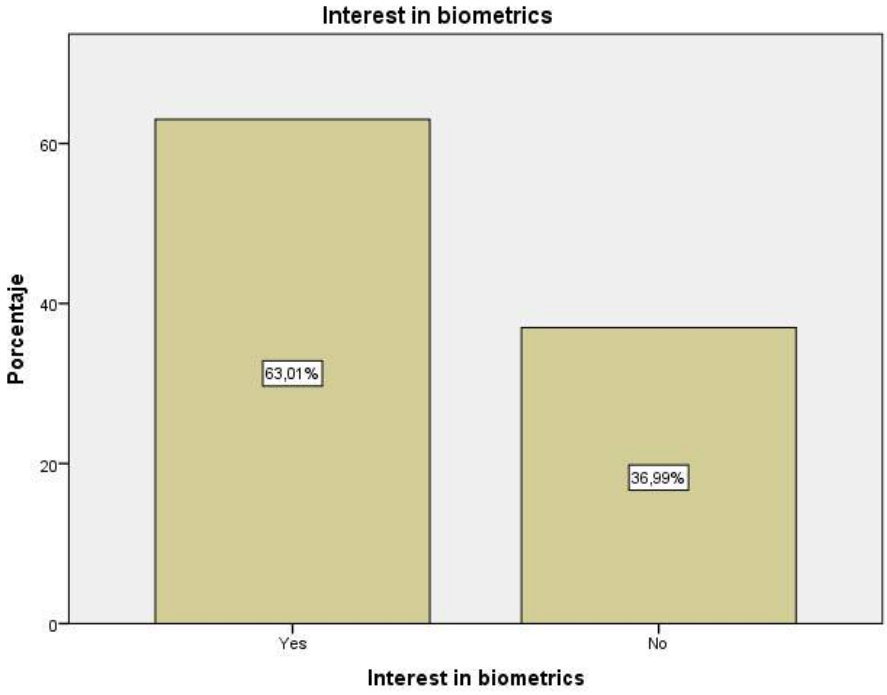
Graph 8. Questionnaire. Perceived usefulness of PPE

Respondents report that they only change their PPE equipment when it breaks or they never renew it. Some of these pieces of PPE might break and the user might not be aware of it, due to wear and tear of inner materials. It might be a good idea to design PPE in a way that users are made aware of when it should be renewed (Graph 9. Questionnaire. Change of PPE).



Graph 9. Questionnaire. Change of PPE

Finally, most respondents showed an interest in including an electronic biometric system measuring body performance through the knee pad itself (Graph 10. Questionnaire. Interest in biometrics). This opens a new possibility for PPE design, giving them a double functionality.



Graph 10. Questionnaire. Interest in biometrics

No direct correlations were found between variables, but this may be due to the small size of the sample. This questionnaire should be repeated with a larger group of skaters to find links between interesting variables.

3.5. Interview

An interview was conducted with Víctor Bermúdez, Rollerblade's brand manager and previously working with Powerslide's design team. He has been an inline skater at a competitive level for many years and in different disciplines, as well as a judge in these competitions. He was chosen for his double profile as an inline skating user and as an inline skating professional. The following are the topics that were discussed and the information that was given by Víctor

ROLLERBLADE DESIGN PROCESS

Before starting the process, an initial meeting is carried out to discuss the new collections and the products that they will include. This is defined by a marketing team, which bases their criteria on the clients' and the shops' needs and comments. When the products are developed, with great attention to detail to obtain the required homologations, and all the documentation is prepared, a final meeting takes place in which these are presented to the rest of the team.

CONTACT WITH CLIENTS

Víctor has direct communication with the final clients, as well as their trainers, representatives or team leaders, through meetings or telephonic conversations. This way, clients are correctly interpreted and they can make their concerns or needs to the company directly.

CRITERIA TO DESIGN PPE

The main concern for designers is to create inexpensive protective equipment. With this in mind, the design of the knee pads cannot exceed the minimum criteria (which, in this case, would be to protect the user's knees). The rest of the desired characteristics of this protective equipment are comfort, lightness and breathability. It is considered that skaters using general protective equipment (as opposed to protective equipment designed for specific disciplines with higher risks, such as roller derby or downhill) do not need as much protection as other types of skaters.

CRITERIA TO DESIGN PPE

The target user is anyone up until the age of around 40 or 45. Beginner skaters tend to buy their first skates, their protective equipment set, including a helmet, and a backpack. This profile tends to wear general equipment, as they are not associated with a particular discipline. Skaters with more experience tend to participate in riskier disciplines, needing specific equipment to protect themselves. This leads to the conclusion that skaters engaging in specific disciplines are usually more experienced. This user profile is also the one linked to a lower use of PPE because they believe that their level is high enough to avoid accidents. They also think that PPE is uncomfortable and they would rather be injured than wear protective equipment during their training.

INICIATIVES TO ENCOURAGE THE USE OF PPE

Rollerblade's efforts are mainly focused on promoting the use of helmets and raising awareness of its importance, as many users assume that wrist guards or knee pads are the most important piece of PPE.

ADVERTISING IN THE ROLLERBLADING INDUSTRY

The most important conclusion that can be drawn from this topic is that an investment in traditional advertising is never considered anymore. It is thought that Internet targeted ads can reach the target user more effectively and for a lower price. The final impact of this advertising tactic is higher than through traditional channels.

3.6. The user

The target user of rollerblading companies, as defined by Víctor Bermúdez in the interview, is anyone up to the age of 40 or 45. Those beyond that age might be customers, but if they are, they would typically be users that started skating with a younger age and have now formed purchasing habits.

This project focuses on the improvement of the ergonomics of knee pads, as well as including an added value which makes the final product more desirable. The target user for these knee pads is a skater profile with more experience than the average user, practising a specific skating discipline with specialised equipment. It is important to note that, although the product does protect the user and safety is one of the main concerns in the design process, the knee pads will be designed to offer tools to improve performance rather than offering extra protection. Therefore, these pads would be more suitable for skaters who do not practice risky disciplines.

3.7. Objectives for knee pads

A well-designed knee pad should excel in function, ergonomics, and preferably aesthetics.

FUNCTION

Knee pads should cover the knee and protect it from impact and sliding. Other functions might be desirable if they are coherent with the context and the user's needs.

ERGONOMICS

They should correctly adapt to the shape of the knee and allow a freedom of movement, making it seem as though the user is not wearing any additional accessories.

AESTHETICS

The design should be appealing to foster the use of PPE and to reduce peer pressure to not wear knee pads.

3.8. Social, cultural and economic factors

3.8.1. Culture and society

One of the main reasons for the lack of use of protective equipment in roller sports is peer pressure (Sherker & Cassell, 2001). The design of new knee pads with attractive aesthetics, as well as a technological aspect to them, can lead to a higher interest in wearing this type of equipment, as well as reducing peer pressure.

PPE could be not thought of as something designed for beginners anymore, but rather, a training tool used only by the elite. By focusing this product on experienced users –who tend to be well-known within the rollerblading community, independently of their discipline- an image of safety will be projected on impressionable users. When idols wear protective equipment, this sends a powerful message to skaters, promoting the use of PPE.

3.8.2. Economy

At the moment, most PPE is sold as a package including wrist guards, knee pads and elbow pads. These can sometimes include a helmet. The cost of this package is, on average, 25€ (Inercia, n.d.). The price is accessible, but by reducing its cost, the quality is also affected.

With a higher budget, the user can find better options on the market, especially when buying pieces of PPE separately. With this project, the final price of the knee pad will be increased, but the overall quality and added value will be clearly visible to the users.

This will not only improve user experience, but by reducing the risk of injuries, especially those that are considered serious, public medical costs will be reduced. This does not only consider the costs of medical care, but also the costs for companies of medical leaves.

3.9. Human anatomy

"The knee is a joint formed, stabilized and given mobility by the articulation of bones, ligaments and tendons. This joint is the largest joint in the body and is formed by the articulation of the femur bone in the thigh with the tibia in the lower leg." (Samuel, n.d.)

The knee is a synovial joint, which can move freely. It falls under the uniaxial type of synovial joint, meaning that it only has one point from which it pivots. It mainly allows for flexion and extension. It can also move in lateral rotation, but this movement is not considered significant.

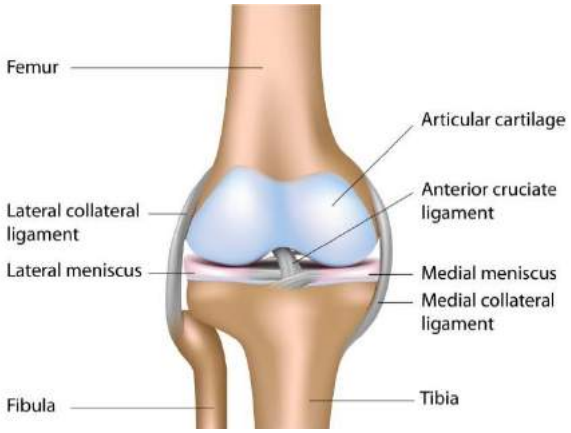


Illustration 18. Anterior view of the right knee (Samuel, n.d.)

This is the largest joint of the body and is a frequent site of pain and injuries in athletes. The knee consists of two articulations, the tibiofemoral (which is the one supporting the weight on the joint) and the patellofemoral (placing a tendon on top of the knee to improve muscle efficiency).

The knee cap covers the front part of the joint, covered by articular cartilage. The menisci cartilage (offering knee stability) is also located here, separating the femur and the tibia, and both cartilages protect the knee against impact.

Finally, the synovial membrane, placed between the moving structures within the knee, produces synovial fluid reducing wear and tear. (O. Jones, 2018; Samuel, n.d.).

3.9.1. Relevant knee injuries

There are several relevant knee injuries, being especially important those derived from sport activities. The first is an injury to the collateral ligaments, caused by a force being applied to the side of the knee forcing it inward, followed by tear in the cruciate ligaments caused by hyperextension of the knee, by twisting it or by a large impact on the back of the joint when the leg is flexed, and these can also lead to fractures. Injuries in the menisci are a result of large impacts. Another possible injury is bursitis, causing swelling on the knee due to friction between the skin and the patella or the tibia, or the unhappy triad, which are injuries to the knee's ligaments due to force from the side when the knee is extended (American Orthopaedic Society for Sports Medicine, 2013; O. Jones, 2018).

3.9.2. Knee range of motion and movements

The knee is a hinge joint in the middle of the leg. It also has a slight rotation movement which is not typically considered. Its movements are flexion, extension (

Illustration 19. Knee range of motion (Singh, n.d.)) (both considered as the main movements of the knee), medial rotation and lateral rotation.

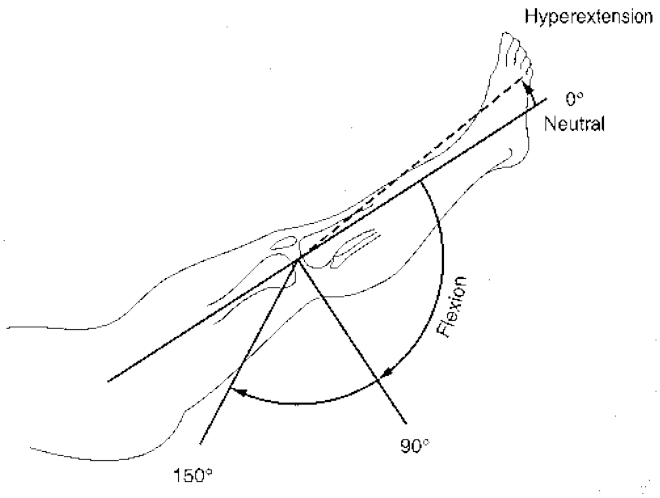


Illustration 19. Knee range of motion (Singh, n.d.)

The normal ranges of movement are the following, although these will vary depending on the person and their characteristics:

Flexion	Internal rotation	External rotation
120-150º	10º	30-40º

Flexion and extension movements take part on the upper part of the knee, while the rotation movements, as previously mentioned, have a small range of motion. These take place on the lower part of the knee. All of these movements can be combined or occur independently.

The muscles in the leg perform the movements affecting the knee joint with the help of tendons connecting them to the bones.

When straightening the leg, the quadriceps muscles contract and pull on the quadriceps tendon. This pulls the patella via the patellar tendon, causing an extension of the knee (Samuel, n.d.; Singh, n.d.).

3.9.3. Anthropometric values

For the anthropometric study, data from two types of sources has been obtained. On the one hand, data from anthropometric tables has been used as a guideline, and on the other hand, size charts from different knee pad manufacturers have been used.

The National Aeronautics and Space Administration (NASA) offers anthropometric values for adults, both for women and for men ('Anthropometry and Biomechanics', n.d.). In the following table (Table 5. Anthropometric values from NASA database), the most relevant measurements are presented.

Table 5. Anthropometric values from NASA database

Measure	Gender	5th percentile	50th percentile	95th percentile
Knee height, sitting	Woman	41.6 cm	45.6 cm	49.5 cm
	Men	52.6 cm	56.7 cm	60.9 cm
Popliteal height	Woman	34.7 cm	38.3 cm	41.9 cm
	Men	40.6 cm	44.4 cm	48.1 cm
Buttock-knee length	Woman	48.9 cm	53.3 cm	57.8 cm
	Men	56.8 cm	61.3 cm	65.8 cm
Crotch height	Woman	65.2 cm	70.6 cm	76.1 cm
	Men	79.4 cm	86.4 cm	93.3 cm
Calf height	Woman	25.5 cm	28.9 cm	32.3 cm
	Men	32.5 cm	36.2 cm	40.0 cm
Buttock-popliteal length	Woman	37.9 cm	41.7 cm	45.5 cm
	Men	46.9 cm	51.2 cm	55.5 cm

Table 6. Anthropometric values from NASA database (continued)

Measure	Gender	5th percentile	50th percentile	95th percentile
Tibiale height	Woman	35.9 cm	39.3 cm	42.7 cm
	Men			
Knee circumference	Woman	31.0 cm	34.6 cm	38.2 cm
	Men	35.9 cm	39.4 cm	42.9 cm
Calf circumference	Woman	30.3 cm	34.1 cm	37.8 cm
	Men	33.9 cm	37.6 cm	41.4 cm

Knee pad manufacturer size charts are presented in the following table (Table 7. Manufacturer knee pad size chart) ('Demon - Knee Pads Size Chart', 2018; 'ProTec Knee Pad Size Chart', 2018; 'Size charts', 2018; 'Sizing chart | Knee protective', 2018; 'Street knee', 2018). The three compared sizes are small, medium and large.

Table 7. Manufacturer knee pad size chart

Company	Measurement	Small (S)	Medium (M)	Large (L)
ProTec	Circumference above knee	30.0 - 36.0 cm	38.0 - 41.0 cm	46.0 - 51.0 cm
	Circumference below knee	23.0 - 28.0 cm	28.0 - 33.0 cm	39.0 - 41.0 cm
Demon	Circumference above knee	39.5 - 42.0 cm	42.0 - 44.5 cm	44.5 - 47.0 cm
	Circumference below knee	33.0 - 35.5 cm	35.5 - 38.0 cm	38.0 - 40.5 cm
187 Killer Pads	Knee joint	30.5 - 35.5 cm	35.5 - 40.5 cm	38.0 - 43.5 cm
iXS Sports Division	Height	160 - 170 cm	170 - 180 cm	180 - 190 cm
	Circumference above knee	38.0 - 40.0 cm	40.0 - 42.0 cm	42.0 - 44.0 cm
	Knee centre to ankle centre	40.0 - 41.0 cm	42.0 - 43.0 cm	44.0 - 45.0 cm
Triple 8	Knee joint	32.0 - 36.0 cm	36.0 - 40.0 cm	40.0 - 44.0 cm

3.10. Conclusions of the research phase

From the research phase, a large amount of data has been collected. This can be used as the basis of this project. As previously explained, the target user is an experienced skater from ages up to 40-45. This user should be interested in new technologies or in improving performance based on data analysis.

From the historical evolution of knee pads, one can tell that most designs look very similar at first glance. After reading each patent, other factors can be recognised. This opens a wide variety of innovation options. By adding new functions or elements to the knee pad, rather than focusing on the aesthetics, a new market can be reached.

The reasons for not using PPE should be kept in mind, to avoid these mistakes in the new design of the knee pads. The main reasons are peer pressure, cost, discomfort, lack of perceived need, appearance and inconvenience. It has been stated that men use less PPE than women, and children less than adults, although extremely low use of PPE can be found across all age groups and experience levels. The recommendations from the bibliographic research for new designs include an attractive and fashionable design, lightweight, overheating prevention, adaptation to different types of users, durable materials, secure fit and possibly including reflective elements.

From the conversation with Víctor Bermúdez and from the questionnaire for skaters, information such as the fact that the use of knee pads lowers as the experience levels increases was found. The lack of use of PPE is, reportedly, due to discomfort, while PPE manufacturers' main focus is protection. An interesting bit of information is that users show an interest in biometrics through knee pads.

4

ANALYSIS OF EXISTING PRODUCTS

4. Analysis of existing products

4.1. General characteristics of a knee pad

There is a large offer of knee pads in the market, from different brands and designed for different disciplines, as well as differing in the degree of complexity of the design. According to UNE-EN 14120-2003+A1-2007 (AENOR, 2007), there are two levels of performance in roller sports protective equipment. These are level 1, including protective equipment for the use of normal roller sports, and level 2, which refers to PPE for acrobatic roller sports.

These, in turn, are divided into three groups for different body mass users. Group A is for users with body mass up to 25 kg, group B is for users with a body mass between 25 kg and up to 50 kg, and group C for users above 50 kg.

Illustration 20. Knee pads (Inercia, n.d.)

There is not a specific design requirement for knee pads other than that it should protect the knee and be comfortable for the user, but most pads have a similar design: they consist of two or three layers, being an external layer with a rigid material, protecting the knee; a second layer in which the main structure is created, including a subjection system; and a final inner layer, which can be combined with the structure layer, offering comfort by means of padding.

4.2. Knee pads in the market

4.2.1. Types of knee pads in the market

Although many brands offer their own line of protective equipment, designs rarely differ. The two main types of knee pads one can find is general PPE, which can be worn by any skater at a low price, and specific PPE, designed for specific skating disciplines and at a higher price.

Not all skating disciplines have their own specialised PPE, and this is due to the demand of skaters. Inline skaters tend to not wear PPE unless required, which means that it is only used in extreme disciplines where not wearing PPE can result in severe injuries.

4.2.2. Main roller sports PPE manufacturers

Based on a study from different online skate shops, a perceptual map was created to represent the main brands selling knee pads ('Protecciones Rodilleras', 2018; 'Rodilleras', 2018a; 'Rodilleras', 2018b; 'Rodilleras', 2018c; 'Rodilleras', 2018d). No PPE packs were considered, and the information of each brand has been obtained exclusively from the products sold on these websites.

Illustration 21. Perceptual map

Taking into account the amount of products sold from each brand, the ones that can be considered as the most relevant in the field are 187 Killer Pads, Ennui, Triple 8, Pro-Tec, G-Form, Powerslide and Rollerblade (in that order).

4.2.3. Analysis of existing solutions

In the following tables, some examples of products sold by each of these main brands are shown (Table 8. Analysis of existing solutions. 187 Killer Pads, Table 9. Analysis of existing solutions. Ennui, Table 10. Analysis of existing solutions. Triple , Table 11. Analysis of existing solutions. Pro-Tec, Table 12. Analysis of existing solutions. G-Form, Table 13. Analysis of existing solutions. Powerslide and Table 14. Analysis of existing solutions. Rollerblade).

Table 8. Analysis of existing solutions. 187 Killer Pads

187 Killer Pads offers protective equipment for skaters on high experience levels ('187 Kill. Pads', 2018).		
Pro Derby Knee Pad	Fly Knee Pad	Knee Gasket
The design, focused on roller derby, offers rigid protection while allowing the user to move appropriately. It has removable foam for easy cleaning.	It is a slim model, reducing the bulkiness of the knee pads. It is a general design for any dangerous roller sports.	These are designed to be worn under the user's clothes. It provides some protection, covering the knee joint completely.

Table 9. Analysis of existing solutions. Ennui

Ennui is a company designing and manufacturing protective equipment for roller sports with no motorised elements, especially urban sports ('Ennui', 2018).		
Elle Knee Gasket	City Gasket	Ally
It uses a removable hard protective material which can be changed if broken or worn out. It is lightweight and breathable.	It is made of stretchable and breathable materials. It allows for freedom of movement and it is resistant to slides. They can be worn under or above clothes.	It absorbs sweat to increase comfort and its thick padding protects the knee and offers comfort.

Table 10. Analysis of existing solutions. Triple Eight

Triple Eight, founded in 1996, is a company made up of young experienced skaters. Their protective equipment is mainly addressed to riskier sports ('Triple 8', 2018).		
KP22	Fly Knee Pad	D-TEC Knee
It is a general design for any dangerous roller sports. They are made of a rigid protective material and a comfort padded layer to protect and offer comfort.		

Table 11. Analysis of existing solutions. Pro-Tec

Pro-Tec, founded in 1973, is a brand proudly linking itself to innovation and youth. Their products are addressed to extreme sports, especially those located in a skate park.	
Street Knee Pads	Double Down Knee Pads
These are designed for skate park sports. It is not bulky and has a flexible body to improve user movement.	The design is made to be placed under the user's clothes. It is extremely stretchable and the hard cap is removable to offer the user the possibility of washing the knee pad.

Table 12. Analysis of existing solutions. G-Form

G-Form, founded by athletes, is an innovative company in which impact protection is the main focus ('G-Form', 2018).	G-FORM

Pro-X

This design is innovative because of the shape of the protective layer. It has different sections that allow the user to move freely while protecting the knee. It is also moisture absorbent and machine washable.

Table 13. Analysis of existing solutions. Powerslide

Powerslide is a very well-known brand within the rollerblading community. The company was founded in 1994, with the inline skating boom ('Powerslide', 2018).	POWERSLIDE

Air Pure

Playlife

Pro Pure

These generic knee pads consist of a highly padded surface placed against the knee for comfort, attached by means of two Velcro straps. The protective layer is a rigid material placed on the most important knee parts.

Table 14. Analysis of existing solutions. Rollerblade

Rollerblade is the other large and well-known company, so much so that even the sport was named after the brand. Rollerblade created a new way of experiencing inline skates, becoming a pioneer in the sector ('Rollerblade', 2018).		
Pro N Activa	Pro Antracita	Urban Knee Pad
These generic knee pads consist of a highly padded surface placed against the knee for comfort, attached by means of two Velcro straps. The protective layer is a rigid material placed on the most important knee parts.		It is addressed to intermediate or experienced skaters, with little protection but better than wearing no PPE. It is mostly flexible and stretchable.

4.3. Conclusions of analysis of existing solutions

This project is centred around level 2 protective knee pads, focused on acrobatic roller sports. Having specialised knee pads allows for a more creative design, including different elements or features that will cover new user needs.

In the perceptual map (Illustration 21. Perceptual map), there was a clear separation (except for some outliers) between specific brands with higher prices and generic brands with lower prices. The goal of this project is to take place amongst the specific designs.

The most sold products are mostly generic. This seems logical, as unexperienced users tend to feel a higher need of using PPE than experienced users. On the other hand, specific knee pads are designed especially for extreme sports. They seem to value comfort over a very high protection, except for roller derby designs, and the knee pads are created to seem less bulky with every new model. G-Form's knee pads are the most different design, dividing the protective material into sections to improve user movement. All this information can be applied on new knee pad designs.

5

PRE-CONCEPTUAL PROPOSAL

5. Pre-conceptual proposal

5.1. Design brief

The goal of this project is to design a knee pad for elite inline skaters who want to improve their performance or simply obtain more information on their training sessions. The desired design should be attractive to users and reduce peer pressure for not wearing PPE. The following are the main requirements for the design.

5.1.1. User

As stated in UNE-EN 14120-2003+A1-2007 (AENOR, 2007), there should be at least three sizes or models to adapt to different users. These are users under 25 kg, users between 25 and 50 kg, and users over 50 kg. This would typically correspond to sizes small, medium and large. The measurements for this design will be based on typical knee pad measurements, as well as anthropometric measurements of the European population.

The target user is someone with experience skating, preferably in a competitive and professional environment related to inline sports, and willing to improve their performance. The product could be mainly used by skaters within large teams, such as national teams, with a high acquisition level and with a very competitive set of mind.

The knee pads will be designed for users practicing acrobatic roller sports, and one the criteria for this type of activity is met, it will satisfy the needs of non-acrobatic roller sports.

5.1.2. Functionality

The knee pad should first of all protect the user from falls or from sliding. There should be at least a protective layer with the main protective material, and a comfort layer with padding or any other means to make the user comfortable. Subjection systems should also be studied to reduce pain or to hold the knee pad in place with a better solution than current Velcro straps. Any solution created should not put the user or other people at risk in any way.

The knee pad should be comfortable and allow for a wide variety of movements so that the training session is not hindered by the use of this PPE.

5.1.3. Aesthetics

The aesthetics of the knee pad have to be as attractive as possible. Two of the main reasons for not wearing PPE are aesthetics and peer pressure (Sherker & Cassell, 2001; Tan et al., 2001; Warda et al., 1998). Skaters do not want to feel as though they are wearing a product that makes them look as beginners, especially in disciplines in which falls are less frequent, and so the design will have to reflect that this is not only a protective measure, but also a training tool.

On the other hand, making a less bulky knee pad can make it less noticeable and this might reduce negative peer pressure. Also, if the knee pad is marketed towards the elite, those who want to reach high levels in the rollerblading community will be more receptive to wearing them.

5.1.4. Electronics

To make the knee pads become a training tool, they have to contain some sort of biometric devices. This will allow to make measurements during the training that will be later shown to the user.

To save energy, the user should have the choice of seeing the data in real time or seeing it after the training session to analyse the results. If the data should be stored for a later time, a memory card will be needed as to not lose any information.

Different functionalities will be discussed throughout the design phase, but the main goal of the electronic circuit is to make measurements that can lead to performance analysis.

5.2. Product specifications

Following, once again, UNE-EN 14120-2003+A1-2007 (AENOR, 2007), the following criteria has been established in order to create a complying design. The final design should also comply with Regulation (EU) 2016-425 (European Parliament & Council of the European Union, 2016) on the marking of the product.

5.2.1. Materials

The materials used and the substances applied should not harm anyone in contact with them. The manufacturer should indicate the main composition of the materials and inform of any potentially dangerous materials.

The protective material should be abrasive and impact resistant, passing the criteria stated in UNE-EN 14120-2003+A1-2007.

5.2.2. Sizes

As previously mentioned, there are three required sizes representing different groups of body mass. These are group A (body mass up to 25 kg), group B (body mass between 25 and 50 kg), and group C (body mass over 50 kg).

5.2.3. Subjection

During normal movements with no impacts, the maximum displacement allowed for the knee pads has been established depending on the size groups.

GROUP A	Maximum displacement of 30 mm
GROUP B	Maximum displacement of 50 mm
GROUP C	Maximum displacement of 60 mm

5.2.4. Resistance to impact

Having established that the design will be addressed to those practicing acrobatic sports, level 2 protective equipment will be created. According to UNE-EN 14120-2003+A1-2007, the following criteria will have to be met (Table 15. Resistance to impact requirements).

Table 15. Resistance to impact requirements

Body mass group						Maximum force peak (kN)
A		B		C		
r	*e*	*r*	*e*	*r*	*e*	
mm	J	mm	J	mm	J	
25	15	35	20	50	25	6

r is the radius of curvature of the anvil

e is the impact energy

6

DESIGN PROCESS

6. Design process

6.1. S.C.A.M.P.E.R.

6.1.1. Tool description

This tool, developed by Alex Osborn and Robert Eberle, has the goal of improving products and services to which it is applied. It is mostly used on existing products, but can also lead to the design of a new product or service from the results of the tool (Mind Tools Content Team, 2018; 'S.C.A.M.P.E.R.', 2018).

Each of the letters of S.C.A.M.P.E.R. represent an analysis of the tool. Their meanings are:

S IS FOR SUBSTITUTE	In which elements of a specific product or service are changed for other options
C IS FOR COMBINE	To combine different ideas or concepts into one, producing a new product or service
A IS FOR ADAPT	To reach a different target group, sector or use with the same product or service
M IS FOR MODIFY	To change a product or service to improve it or to add value to it
P IS FOR PUT TO ANOTHER USE	In which functional alternatives are studied to examine the possibilities of the product or service
E IS FOR ELIMINATE	To analyse the different elements creating the studied product or service to check whether some of them can be discarded
R IS FOR REVERSE	To change elements or move them around to create something different

The solutions that come up with this tool do not have to be complementary. In the final stage of this tool, solutions are chosen based on their viability, added value and interest for the market.

6.1.2. Tool application

S IS FOR SUBSTITUTE	On the basic knee pads, the straps can be substituted by a compression sock, whilst on the medium and complex knee pads, the compression sock can be substituted by straps; Velcro can be substituted by straps with a better subjection system; the rigid protection piece can be substituted by a non-Newtonian material
C IS FOR COMBINE	The knee pads could connect with smartwatches or activity bands, monitoring the physical state of the user; combining the knowledge of a trainer with the knee pads, data can be collected which can be later translated into training tips, shown on a website or app; combining the knowledge of protective equipment experts with the knee pads, it would be possible to detect non-visual wear and tear on the protective equipment

A IS FOR ADAPT	The user could have the choice of subjecting the knee pad with a compression sock or with straps; the user should be able to decorate or customise the knee pads to their own taste; the design of the knee pads should adapt to different sizes (width and length), by adapting or by designing different sizes; the sides of the knee could be protected by adding more material to the knee pads (or redistributing it) to protect the user from injuries from different skating modalities
M IS FOR MODIFY	A function could be added to prevent muscular injuries by heating the muscles before starting the activity, for example; the rigid protective part could cover the sides of the knee; magnifying the reach of activity bands could allow the user to monitor more movements than what is currently being done; the monitoring elements should be directly linked to an activity band, to obtain more data in one go and reducing the need of sensors
P IS FOR PUT TO ANOTHER USE	The knee pads could monitor the state of the knee; it could also monitor the physical state of the user (muscle strain, injuries, heart rate…); it could measure the knee temperature to check whether the user has warmed up or not, and if not, set an alarm to let the user know they should; the sensors included in the knee pad should be able to connect with a smartwatch, smartphone or PC via Wi-Fi or Bluetooth
E IS FOR ELIMINATE	Either the straps or the compression sock could be eliminated
R IS FOR REVERSE	The protective element could be relocated to cover more knee surface; increasing its size could also help cover more surface; if the rigid material had divisions, it would allow for more freedom of movement

6.2. Visual and functional inconsistencies

6.2.1. Tool description

Firstly described by Ch. Jones (C. Jones, 1982), this tool guides a (mostly) visual exploration of a product, analysing and detecting inconsistencies in the design (shape or functionality). Once the inconsistencies are identified, the researcher must propose possible causes for these flaws. This way, on the final step, proposing corrections for these inconsistencies, it is easier to understand why the product is done a certain way and how to improve it.

6.2.2. Tool application

The tool has been applied to the three different types of knee pads (basic, medium and complex). Each of the parts of these protective elements have been identified and analysed to create new solutions.

6.2.2.1. Basic knee pad

Table 16. S.C.A.M.P.E.R. Basic knee pad: Basic description of the object

Component		Function
1	Straps	Hold the knee pad in place and adapt its size to the user's knee
2	Pad	Make the knee pad more comfortable for the user by softening the contact between the skin and the protective material
3	Protection	Protect the user's knee against impact or sliding

Illustration 22. S.C.A.M.P.E.R. Basic knee pad: Components (Inercia, n.d.)

Table 17. S.C.A.M.P.E.R. Basic knee pad: Visual inconsistencies

Visual inconsistencies	Affected component	
Small straps which can cut or burn the user's skin, especially when sweating	1	Straps
Velcro curves after repeated use	1	Straps
Material wear after repeated use	2, 3	Pad and protection
Protection offered only to the centre of the knee	3	Protection

Table 18. S.C.A.M.P.E.R. Basic knee pad: Functional inconsistencies

Functional inconsistencies	Affected component	
Velcro can be easily removed (unsafe subjection)	1	Straps
Straps may slide down if not attached correctly	1	Straps
Straps may cut or burn the user's skin if attached too strong	1	Straps
Not breathable material causing excessive sweat	2, 3	Pad and protection
The material can accumulate bacteria if the user does not clean it often enough	2	Pad
The material is too thick and it can become an obstacle when performing some movements	2	Pad
The material does not adapt to complex movements	2, 3	Pad and protection

Table 19. S.C.A.M.P.E.R. Basic knee pad: Possible causes for visual inconsistencies

Visual inconsistencies	Possible causes
I1. Small straps which can cut or burn the user's skin, especially when sweating	C1. Save material by reducing the size of the straps C2. Anthropometric values not studied correctly C3. Straps designed for child's size
I2. Velcro curves after repeated use	C4. The material choice might not be the best for this use
I3. Material wear after repeated use	C5. The material choice might not be the best for this use C6. The quality of the sewing might not be as good as needed C7. Sliding was not considered during the design process C8. Sliding was not considered during the design process
I4. Protection offered only to the centre of the knee	C9. Anthropometric values not studied correctly C10. Protective part designed for child's size C11. The material choice might not be the best for this use C12. Sliding was not considered during the design process

Table 20. S.C.A.M.P.E.R. Basic knee pad: Possible causes for functional inconsistencies

Functional inconsistencies	Possible causes
I5. Velcro can be easily removed (unsafe subjection)	C13. The material choice might not be the best for this use
I6. Straps may slide down if not attached correctly	C14. The subjection method might not be the most appropriate one for this application C15. Anthropometric values not studied correctly
I7. Straps may cut or burn the user's skin if attached too strong	C16. The subjection method might not be the most appropriate one for this application C17. Anthropometric values not studied correctly
I8. Not breathable material causing excessive sweat	C18. The material choice might not be the best for this use
I9. The material can accumulate bacteria if the user does not clean it often enough	C19. The colours offered don't let the user see that the pad is dirty C20. The pad cannot be separated from the other elements, making it difficult to wash
I10. The material is too thick and it can become an obstacle when performing some movements	C21. Comfort was the main concern when designing the knee pad
	C22. The material choice might not be the best for this use
I11. The material does not adapt to complex movements	C23. The design is not flexible enough to allow for a variety of movements C24. The design considered occasional or recreative skaters

Table 21. S.C.A.M.P.E.R. Basic knee pad: Proposed solutions for visual inconsistencies

Visual inconsistencies	Possible causes	Improvement proposals
I1. Small straps which can cut or burn the user's skin, especially when sweating	C1. Save material by reducing the size of the straps C2. Anthropometric values not studied correctly C3. Straps designed for child's size	P1. Study anthropometric values and create different sizes to adapt to more users P2. Create a system that adapts to different sizes without being uncomfortable for users on the extremes
I2. Velcro curves after repeated use	C4. The material choice might not be the best for this use	P3. Re-study the material choices to check whether there are better options
I3. Material wear after repeated use	C5. The material choice might not be the best for this use C6. The quality of the sewing might not be as good as needed C7. Sliding was not considered during the design process C8. Sliding was not considered during the design process	P4. Re-study the material choices to check whether there are better options P5. Improve sewing quality P6. Reduce sewing to a minimum, use other systems to hold the textiles P7. Use materials other than textiles P8. Choose other materials that increase comfort but not the thickness of the pad P9. Optimise the thickness of the pad P10. Choose a material that is resistant to friction P11. Choose a design that does not show the wear of the protection when sliding
I4. Protection offered only to the centre of the knee	C9. Anthropometric values not studied correctly C10. Protective part designed for child's size C11. The material choice might not be the best for this use C12. Sliding was not considered during the design process	P12. Choose a material that is resistant to friction P13. Study anthropometric values and create different sizes to adapt to more users P14. Increase the surface of protection to cover the sides of the knee

Table 22. S.C.A.M.P.E.R. Basic knee pad: Proposed solutions for functional inconsistencies

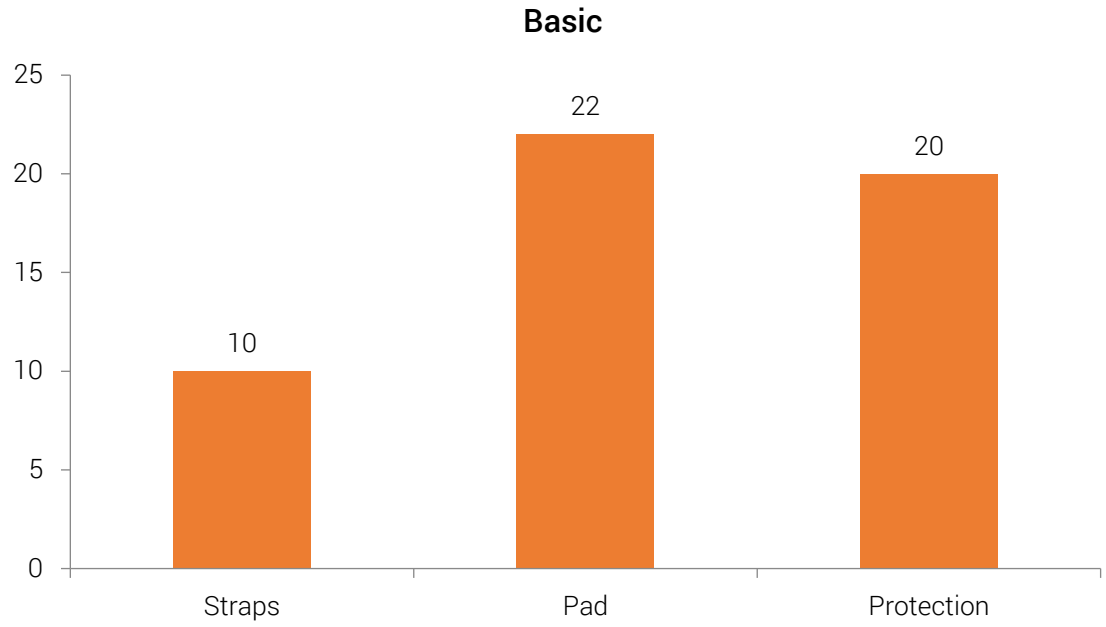
Functional inconsistencies	Possible causes	Improvement proposals
I5. Velcro can be easily removed (unsafe subjection)	C13. The material choice might not be the best for this use	P15. Re-study the material choices to check whether there are better options
I6. Straps may slide down if not attached correctly	C14. The subjection method might not be the most appropriate one for this application C15. Anthropometric values not studied correctly	P16. Study anthropometric values and create different sizes to adapt to more users P17. Create a system that adapts to different sizes without being uncomfortable for users on the extremes P18. Re-study the material choices to check whether there are better options
I7. Straps may cut or burn the user's skin if attached too strong	C16. The subjection method might not be the most appropriate one for this application C17. Anthropometric values not studied correctly	P19. Study anthropometric values and create different sizes to adapt to more users P20. Create a system that adapts to different sizes without being uncomfortable for users on the extremes P21. Re-study the material choices to check whether there are better options
I8. Not breathable material causing excessive sweat	C18. The material choice might not be the best for this use	P22. Re-study the material choices to check whether there are better options P23. Choose other materials that increase comfort but not the thickness of the pad P24. Optimise the thickness of the pad
I9. The material can accumulate bacteria if the user does not clean it often enough	C19. The colours offered don't let the user see that the pad is dirty C20. The pad cannot be separated from the other elements, making it difficult to wash	P25. Choose colours that show the state of the pad (clean or dirty), depending on humidity P26. Choose soft colours that let the user see whether the pad is wet or not

Table 23. S.C.A.M.P.E.R. Basic knee pad: Proposed solutions for functional inconsistencies (continued)

Functional inconsistencies	Possible causes	Improvement proposals
I10. The material is too thick and it can become an obstacle when performing some movements	C21. Comfort was the main concern when designing the knee pad	P27. Choose other materials that increase comfort but not the thickness of the pad P28. Re-study the material choices to check whether there are better options P29. Optimise the thickness of the pad
I11. The material does not adapt to complex movements	C22. The material choice might not be the best for this use C23. The design is not flexible enough to allow for a variety of movements C24. The design considered occasional or recreational skaters	P30. Re-study the material choices to check whether there are better options P31. Choose a material that is resistant to friction P32. Choose a design that does not show the wear of the protection when sliding P33. Study anthropometric values and create different sizes to adapt to more users P34. Create a design that is adaptable to different rollerblading modalities (modules or adaptive protection) P35. Choose a material that is resistant to friction

Table 24. S.C.A.M.P.E.R. Basic knee pad: Results

Concept	TOTAL
Visual inconsistencies	4
Functional inconsistencies	7
Possible causes	24
Improvement proposals	35



Graph 11. S.C.A.M.P.E.R. Basic knee pads: Possible improvements for each component

6.2.2.1. Medium and complex knee pad

These two types of knee pads are very similar, so the analysis has been done for both at the same time.

Table 25. S.C.A.M.P.E.R. Medium knee pad: Basic description of the object

Component		Function
1	Straps	Hold the knee pad in place and adapt its size to the user's knee
2	Pad	Make the knee pad more comfortable for the user by softening the contact between the skin and the protective material
3	Compression pad	Help hold the knee pad on the knee correctly and prevent muscular pain on knee
4	Protection	Protect the user's knee against impact or sliding

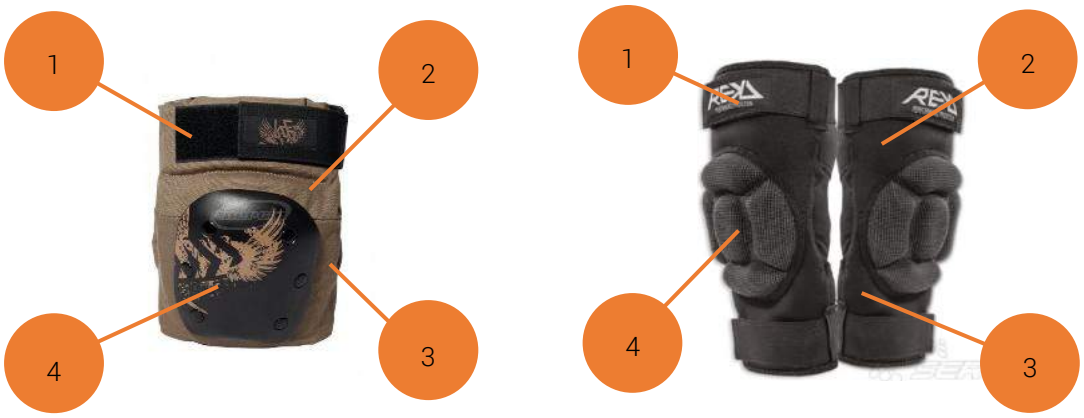


Illustration 23. S.C.A.M.P.E.R. Medium knee pad: Components (Inercia, n.d.)

Table 26. S.C.A.M.P.E.R. Medium knee pad: Visual inconsistencies

Visual inconsistencies	Affected component	
I1. Velcro curves after some uses	1	Straps
I2. Material wear after a few uses	2, 3, 4	Pad, compression sock and protection
I3. It only protects a small knee and does not cover its sides	4	Protection
I4. Easily scratched and consumed	4	Protection

Table 27. S.C.A.M.P.E.R. Medium knee pad: Functional inconsistencies

Functional inconsistencies	Affected component	
I5. Velcro can be easily removed	1	Straps
I6. The material is not breathable and causes excessive sweat	2, 3	Pad and compression sock
I7. The material can accumulate bacteria if the user does not clean it often enough	2, 3	Pad and compression sock
I8. Has to be placed before the skates and this might be an inconvenience when the user forgets to wear them	3	Compression sock

Table 28. S.C.A.M.P.E.R. Medium knee pad: Functional inconsistencies (continued)

Functional inconsistencies	Affected component	
I9. The compression sock has to fit the user perfectly for comfortable use	3	Compression sock
I10. Uncomfortable when straightening the leg (medium)	2, 4	Pad and protection
I11. The surface of contact of the compression sock is excessive, causing sweat (complex)	3	Compression sock
I12. The protective material can only be used for certain rollerblading modalities (complex)	4	Protection

Table 29. S.C.A.M.P.E.R. Medium knee pad: Proposed solutions for visual inconsistencies

Visual inconsistencies	Possible causes	Improvement proposals
I1. Velcro curves after some uses	C1. Anthropometric values not studied correctly C2. The material choice might not be the best for this use	P1. Re-study the material choices to check whether there are better options
I2. Material wear after a few uses	C3. The material choice might not be the best for this use C4. The quality of the sewing might not be as good as needed C5. Sliding was not considered during the design process	P2. Re-study the material choices to check whether there are better options P3. Reduce sewing to a minimum, use other systems to hold the textiles P4. Use materials other than textiles
I3. It only protects a small knee and does not cover its sides	C6. Anthropometric values not studied correctly C7. The design considered the protection of the knee exclusively	P5. Study anthropometric values and create different sizes to adapt to more users P6. Create a system that adapts to different sizes without being uncomfortable for users on the extremes P7. Increase the surface of protection to cover the sides of the knee

Table 30. S.C.A.M.P.E.R. Medium knee pad: Proposed solutions for visual inconsistencies (continued)

Visual inconsistencies	Possible causes	Improvement proposals
I4. Easily scratched and consumed	C8. The material choice might not be the best for this use C9. Sliding was not considered during the design process	P8. Choose a material that is resistant to friction P9. Choose a design that does not show the wear of the protection when sliding

Table 31. S.C.A.M.P.E.R. Medium knee pad: Proposed solutions for functional inconsistencies

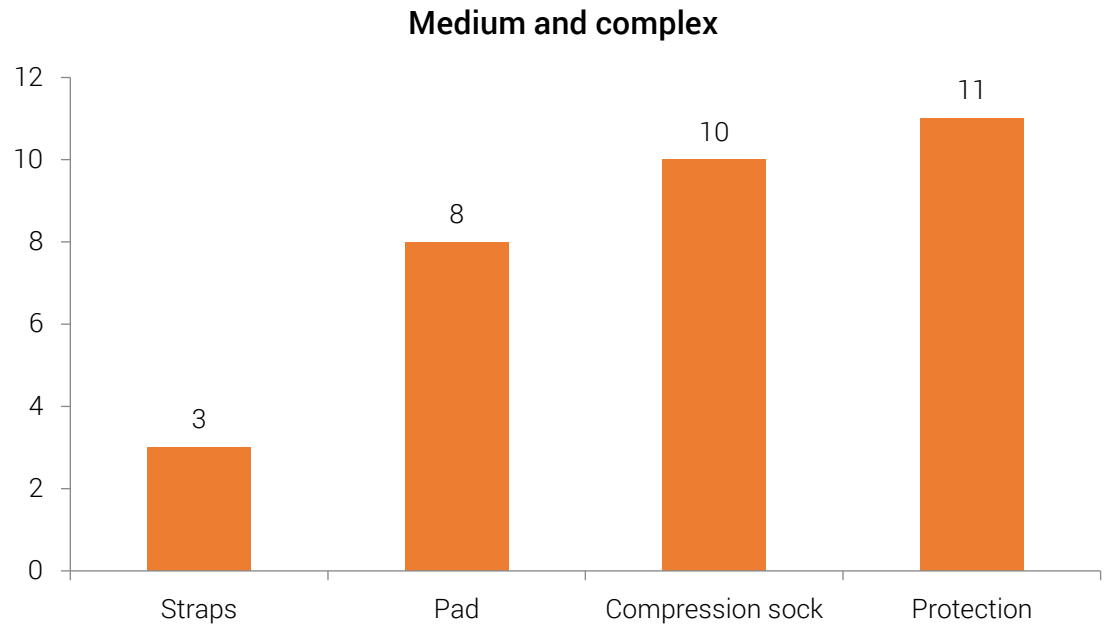
Functional inconsistencies	Possible causes	Improvement proposals
I5. Velcro can be easily removed	C10. The material choice might not be the best for this use	P10. Re-study the material choices to check whether there are better options P11. Study anthropometric values and create different sizes to adapt to more users
I6. The material is not breathable and causes excessive sweat	C11. The material choice might not be the best for this use	P11. Choose other materials that increase comfort but not the thickness of the pad P12. Optimise the thickness of the pad
I7. The material can accumulate bacteria if the user does not clean it often enough	C12. The colours offered don't let the user see that the pad is dirty C13. The pad cannot be separated from the other elements, making it difficult to wash	P13. Choose colours that show the state of the pad (clean or dirty), depending on humidity P14. Choose soft colours that let the user see whether the pad is wet or not

Table 32. S.C.A.M.P.E.R. Medium knee pad: Proposed solutions for functional inconsistencies (continued)

Functional inconsistencies	Possible causes	Improvement proposals
I8. Has to be placed before the skates and this might be an inconvenience when the user forgets to wear them	C14. It was designed as an alternative to traditional simple knee pads C15. The main concern in the design phase was to make the knee pad to hold itself correctly	P15. Create a system that adapts to different sizes without being uncomfortable for users on the extremes
I9. The compression sock has to fit the user perfectly for comfortable use	C16. It was designed as an alternative to traditional simple knee pads	P16. Create a system that adapts to different sizes without being uncomfortable for users on the extremes
I10. Uncomfortable when straightening the leg (medium)	C17. The design is not flexible enough to allow for a variety of movements C18. The design considered occasional or recreational skaters C19. The main concern in the design phase was to make the knee pad to hold itself correctly	P17. Create a design that is adaptable to different rollerblading modalities (modules or adaptive protection)
I11. The surface of contact of the compression sock is excessive, causing sweat (complex)	C20. The main concern in the design phase was to make the knee pad to hold itself correctly	P18. Re-study the material choices to check whether there are better options
I12. The protective material can only be used for certain rollerblading modalities (complex)	C21. The design considered occasional or recreational skaters C22. The design considered rollerbladers from very specific modalities in which impact is a factor but sliding is not C23. The needs of different rollerblading modalities cannot be solved in one product	P19. Choose a material that is resistant to friction P20. Create a design that is adaptable to different rollerblading modalities (modules or adaptive protection)

Table 33. S.C.A.M.P.E.R. Basic knee pad: Results

Concept	TOTAL
Visual inconsistencies	4
Functional inconsistencies	8
Possible causes	23
Improvement proposals	20



Graph 12. S.C.A.M.P.E.R. Basic knee pads: Possible improvements for each component

6.3. Brainstorming in five minutes

6.3.1. Tool description

When in the design phase, many proposals can be created and the design process may never end. Sometimes there is no inspiration and it is difficult to come up with solutions. With this tool, the researcher is forced to think of as many proposals as possible in as little as five minutes. With the time limit, only the best ideas make it on the paper, and with the obligation to write something down, uninspired researchers are forced to think of different options.

6.3.2. Tool application

This technique was applied twice to obtain quick ideas in a short span of time. The results were the following:

- Knee pads that are completely open on the back to allow for better breathability
- Rigid protective material is adaptable and padded, covering the sides of the knee (similar to a compression sock that covers everything)
- Non-visual wear alerts of the knee pads to let the user know that they should be replaced
- Adaptable aesthetics using Velcro, colours and prints; space to insert your own design; organic and futuristic shapes
- Knee pads adaptable not only to the thickness of the leg but also the height of the knee
- Measure pulse (to count calories?) at the back of the knee, connecting the data to a smart watch or a smartphone
- Measure the amount of germs/bacteria in the knee pad and alert the user when they should be washed
- Measurement results in graphs, both in an app and in a website (so users can check the data on whatever device they feel most comfortable with)
- Measurements of possible injuries in the knee (*see helmets with head injury control and damage on the helmet itself)
- NFC to allow for instant data collection on phone in case of accident
- Measure whether the user has done a warm-up and alert in case they are performing risky movements due to unprepared muscles

6.4. Electronic design

Having studied the main commercialised knee pads, functionalities were though of to be included in the new design. These were based on other biometric systems (such as activity bands) and other user needs when training. Some of these functionalities were included in the final design and some others were not.

CONNECTIVITY WITH MOBILE PHONES, COMPUTERS OR ACTIVITY BANDS

This would increase the energy consumption of the product, but it would reduce the steps that the user would have to take to receive the information collected by the sensors, allowing them to receive real-time data. Also, with the possibility of turning on and off this module, the user could choose when to transfer the information and maybe use it only when charging the device.

HEART RATE SENSOR

When training, it is important to have some control over the heart rate. This allows the user to adjust the intensity of the activity to their possibilities and their goals. The ideal heart rate when practising sports should be at around 60-80% of the maximum heart rate, starting at a safe rate of 60-70% (Hottenrott, 2007). As can be seen in the following image (Illustration 24. Pulse points ('Firmax3', n.d.)), the knee pad is an ideal instrument to measure the heart rate, as it can use the back side of the knee (an ideal place to measure pulse).

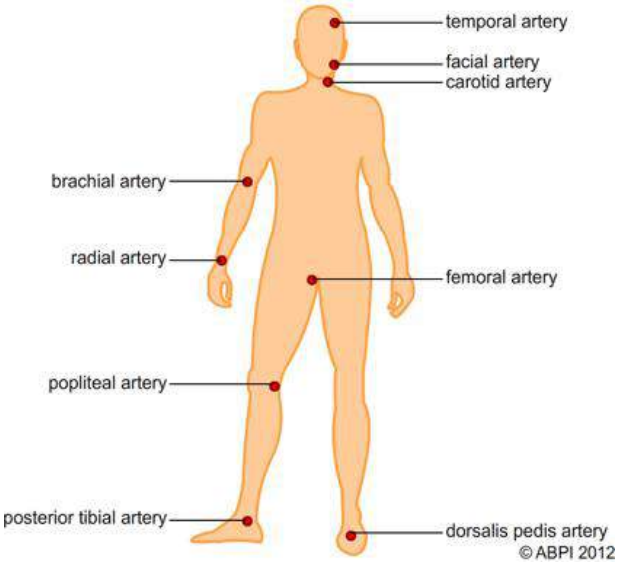


Illustration 24. Pulse points ('Firmax3', n.d.)

SPEED, DISTANCE AND CHANGE OF ALTITUDE

Some skating disciplines require high speed or long-distance journeys, in which it is interesting to monitor the final performance. This is already being applied to runners and cyclists, for example, but it can have very high energy consumption when using GPS to track the path that is being followed.

CALORIES BURNED

It might be interesting for the user to know the calories that have been burned throughout the workout. This will probably be a functionality more interesting for those practising the sport to exercise rather than those who train at a competitive level. This data can be obtained by using the heart rate sensor and some basic user information, and then applying a formula.

HUMIDITY SENSORS

This could indicate when too much sweat is held in the knee pad and notify the user to clean it before using it again. There could also be some sort of bacteria sensors to identify when it would be unhygienic to use the knee pads.

IMPACT SENSORS

In sports in which falls are more frequent, an impact sensor could identify the amount of times in which the knee has suffered any strain and maybe show the position of the impact in a diagram when the information is sent to portable devices. This concept is currently being used in American football helmets, to prevent concussions ('Impact Sensors for Helmets', 2017; 'Shockbox: Sports Helmet Sensors', 2018; Lench, n.d.).

THICKNESS MEASUREMENTS OF PROTECTIVE MATERIAL

By measuring the amount of material protecting the knee, the user can be alerted when the material is too thin and might not protect as well as it did before.

ACTIVITY OF MUSCLE MEASUREMENTS

This ('Electromyography Sensor (EMG) for e-Health Platform [Biometric / Medical Applications]', n.d.) could help the user know, on a more technical level, the performance of the muscles on the

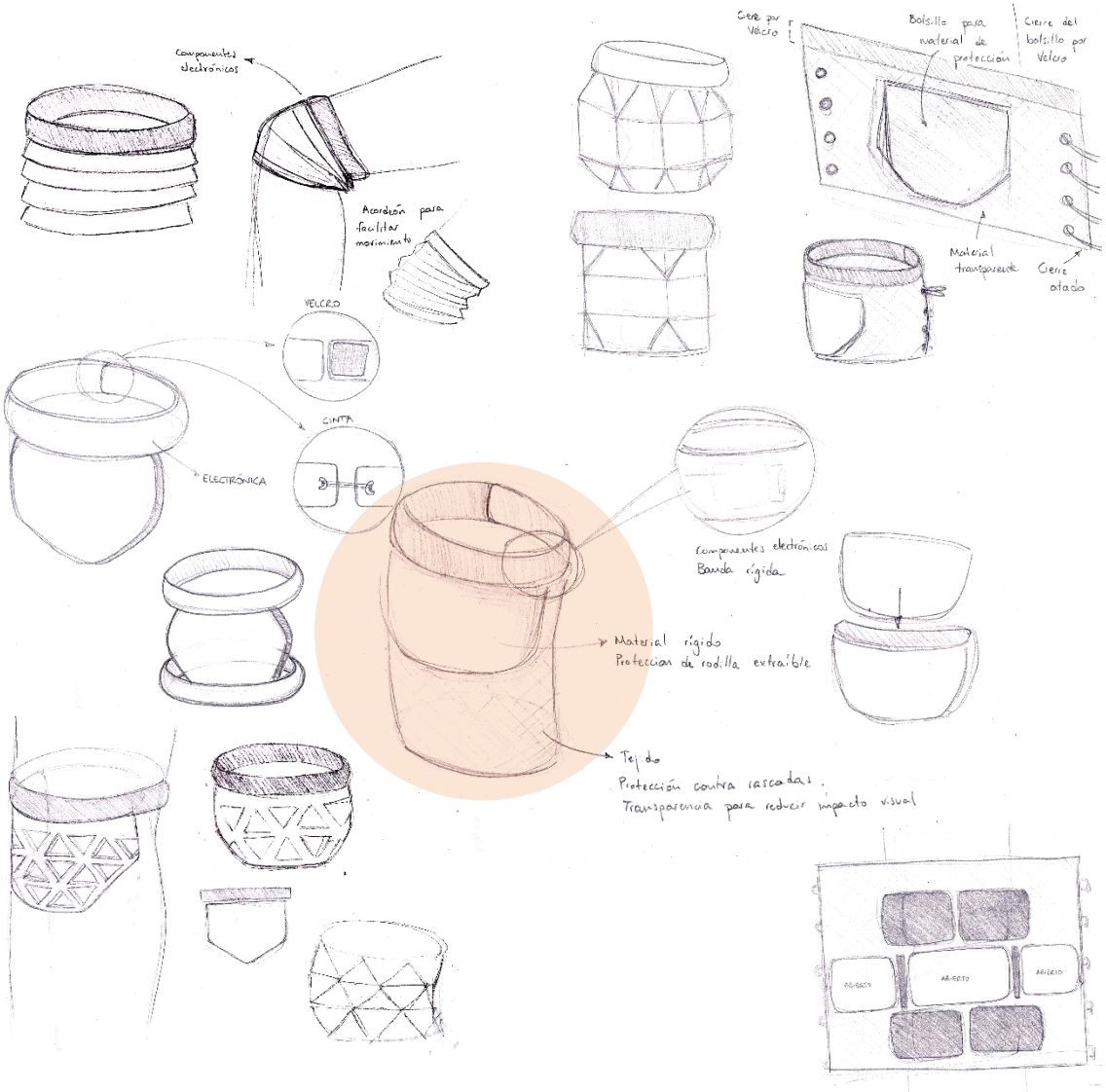
leg when training. It could be done by using a force-sensitive sensor by measuring the force of the muscles against the knee pad ('Round Force-Sensitive Resistor (FSR) - Interlink 402', n.d.), but it could also be misleading when falls occur, or by using resistance sensors ('Eeonyx Stretchy Variable Resistance Sensor Fabric - LTT-SLPA-20K', n.d.).

BODY TEMPERATURE

With this measurement, the user could know if the knee is warmed up and if the muscles are ready for the training ('Body Temperature Sensor for e-Health Platform [Biometric / Medical Applications]', n.d.). The portable device of the user's choice would show the normal parameters and help do a correct warm up session. This could also lead to problems if the temperature is measured all the time or if the environment temperature is not taken into account.

6.5. Conclusions of the design process

With the information gathered throughout the design process, prior to, during and after analysing the data, sketches were made. These reflect the ideas presented in the previous stages and explore different possibilities.



Electrónica
Malla
Protección en bolsillo
Pieza rígida
VELCRO?
Sistema de unión
Estructura rígida
Velcro
Protección
Malla para respirabilidad
Unión flexible
Libertad de movimiento
Unión por los laterales
VELCRO
VISTA LATERAL
VISTA FRONTAL
VISTA SUPERIOR

7

CONCEPTUAL DESIGN

7. Conceptual design

7.1. Electronic design

Assessing the positive and negative aspects of each of the components, the most important ones, or the ones perceived as those most useful to the user, were chosen. The final chosen functionalities are the following.

KNEE MOVEMENT TRACKING

By using inertial measurement units (IMUs), which are electronic components allowing to measure body movements by means of accelerometers and gyroscopes ('Inertial measurement unit', 2018), the movements of the knee can be tracked. These are mainly used, in this case, to register the amount of times and the degrees to which the knee is bent throughout the training session. These results can then be used by professional skaters to reduce the strain that the knee has to suffer. The chosen component for this function is Sparkfun 9DoF sensor stick ('SparkFun 9DoF Sensor Stick', n.d.). It can be later used for a more detailed movement information gathering, such as speed or tracking a route by using GPS.

MUSCLE STRAIN

By using a stretchy variable resistance sensor fabric, LTT-SLPA-20K ('Eeonyx Stretchy Variable Resistance Sensor Fabric - LTT-SLPA-20K', n.d.), can identify the changes in resistance when it is stretched. This can help identify the efforts of the muscles around the knee and can help the skater or their trainer to identify which movements are causing high efforts on the legs.

PULSE SENSOR

Sensor SEN-11574 from Sparkfun ('Pulse Sensor', n.d.) identifies the user's pulse and can help adapt the training to the user's possibilities. As mentioned previously, the ideal heart rate when practising sports should be at around 60-80% of the maximum heart rate (Hottenrott, 2007) and one of the best places to measure the pulse is behind the knee, making this the ideal element for the knee pad.

TEMPERATURE SENSOR

By applying a temperature sensor, the user can control their body temperature and adapt the training to this information. LMT70 sensor ('LMT70', 2018) can identify the knee's temperature and, by comparing it to the environmental temperature, it could calculate the ideal point in which the user has warmed up and is ready for a strong training session.

MEMORY CARD

The knee pad will use a memory card to register the data and save it for one training session, giving the user the freedom of choosing whether they need real-time data or whether they prefer viewing it after the training session. This will help save energy and make the knee pad electronic system last longer. The chosen component is Adafruit microSD card breakout board ('Adafruit microSD card breakout board', n.d.).

CONNECTIVITY

Still, if the user is interested in receiving real-time data, a CC2640R2F Bluetooth module ('CC2640R2F', n.d.) is included, which works as the Bluetooth link between the portable device and the knee pad, but also as the microcontroller for the whole electronic system.

7.1.1. Energy consumption

The following calculations take into account the worst case possible to make sure that all cases are covered (Table 34. Energy consumption).

Table 34. Energy consumption

	Application	Voltage	Current	Power
Sparkfun 9 DoF sensor stick	Knee movement tracking	3.3 V	4.6 mA	15.18 mW
Sparkfun 9 DoF sensor stick	Knee movement tracking	3.3 V	4.6 mA	15.18 mW
LTT-SLPA-20K	Muscle strain			
Pulse sensor	Pulse	5.0 V	4.0 mA	20.00 mW
LMT70 sensor	Body temperature	5.5 V	5.0 mA	27.50 mW
Adafruit microSD card breakout board	Memory card holder	3.6 V	100.0 mA	360.00 mW
CC2640R2F	Bluetooth module and microcontroller	4.1 V	9.1 mA	37.31 mW
	TOTAL	24.8 V	127.3 mA	475.17 mW

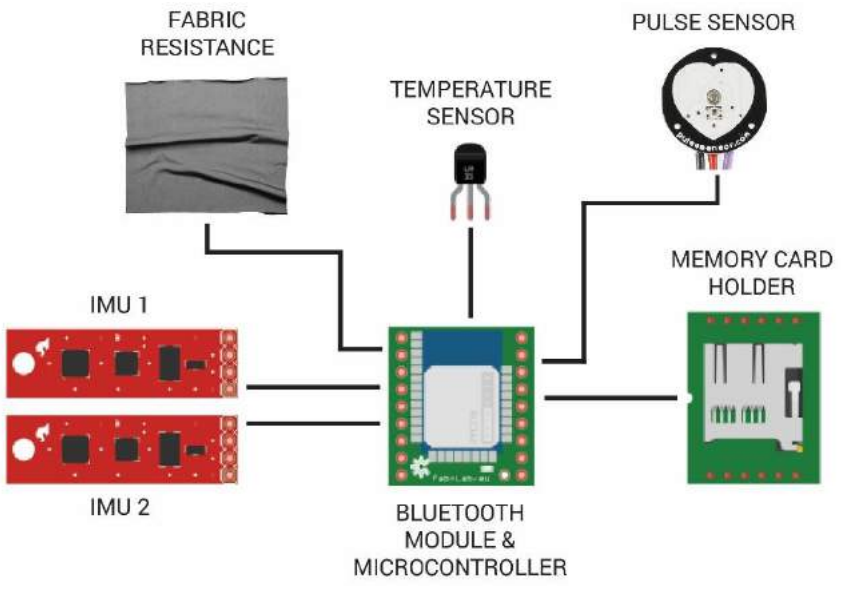
7.1.2. Required memory

The following calculations (Table 35. Required memory) take into account the worst case possible to make sure that all cases are covered.

Table 35. Required memory

	Application	Required memory (worst case)
Sparkfun 9 DoF sensor stick	Knee movement tracking	9 byte
Sparkfun 9 DoF sensor stick	Knee movement tracking	9 byte
LTT-SLPA-20K	Muscle strain	
Pulse sensor	Pulse	1 byte
LMT70 sensor	Body temperature	2 byte
Adafruit microSD card breakout board	Memory card holder	
CC2640R2F	Bluetooth module and microcontroller	
	TOTAL	21 byte
	A 32 Mb memory card will be required to cover all cases	

7.1.3. Electronic circuit



7.2. Body design

The chosen knee pad design is the smallest possible, covering new angles of the knee. It protects the external side of the knee, and partly covers the inner side. It is based on a compression sock design, using two Velcro straps to fasten it into place.

Illustration 25. Final design

It is made up of three layers: the first is a textile holding the materials in place and limiting the protective material's movement. The second is the protective material itself. Finally, the inner layer offers comfort and separates the knee from the other materials. This is also the layer that can measure the efforts of the muscles.

7.2.1. Details

The Velcro straps have a small detail showing the brand logo, in a shape that is similar to a wing, giving the impression that it is linked to speed. This is a way of communicating that the knee pads can help perform better rather than being an obstacle to a better training session. This logo will be further developed and explained in the Formal design chapter.

Illustration 26. Velcro strap detail

The Velcro straps are also used as compression straps, to help with knee injuries. This is especially helpful for elite skaters who practice at high intensity, reducing the strain of this joint ('Cinta rotuliana – Qué es, para qué sirve y mejores modelos', n.d.; Lady Fitness, 2018).

8

MATERIALS AND MANUFACTURING

8. Materials and manufacturing

8.1. Materials

For the material choice, a decision matrix was used, pondering the positive and negative characteristics of each material to obtain the ideal one for the final application. The information, unless otherwise referenced, has been obtained from CES Edupack software, or from estimations based on other products or applications.

8.1.1. External layer

The external layer holds the others in place, as well as being the main body of the knee pad. The material used in this case is a thin fabric which is also elastic. The pocket for the protective material will have a Velcro strap, and the rest of the fabric will have padding sewn to it.

Subjection Velcro straps will be riveted and stuck to artificial leather straps.

8.1.2. Protective layer

The protective layer is possibly the most important layer of the protective equipment. It should be a strong material which will absorb impacts and resist slides so that the user's knee does not suffer. Some of the most common plastics in impact resistant applications have been compared ('Top 3 Most Impact Resistant Plastics', 2017).

Table 36. Decision matrix. Protective layer

	Hardness 10%	Impact resistant 40%	Tensile strength 10%	UV resistant 10%	Density 15%	Cost (approx.) 5%	Pondered score 100%
Acrylonitrile butadiene styrene (ABS)	8.9 - 13.2 HV	7.9 - 63 kN	30 - 50 MPa	Poor	1020 - 1080 kg/m^3	1.85 €/kg	5.0
	10	4	9	3	5	9	
Polycarbonate plastic	90 - 100, Shore A	8 - 10 kN	46 - 66 MPa	Fair	1170 - 1230 kg/m^3	3.82 €/kg	5.5
	7	5	10	6	5	8	
IM LITE (FE001)	82, Shore A	28.3 kN	7.7 Mpa	Good	500 - 700 kg/m^3	4.50 €/kg	7.5
	9	10	4	10	6	7	

The chosen protective material is a D3O protector, commonly used for motorcycle protectives. It is a light material which is also quite flexible, and will absorb high impacts, protecting the user from falls and slides.

8.1.3. Comfort layer

For the comfort layer, one of the electronic components is used as base. It is a resistor in the shape of a textile, collecting the data of the efforts suffered to detect muscle strain. Foam will be placed against the protective material to offer more comfort. This material should have similar elastic properties to those of the protective layer.

8.2. Manufacturing

8.2.1. External layer

The external layer is mostly made up of a thin fabric with a pocket for the protective material. It should also have foam sewn to it for comfort. The manufacturing process here described is related to the artificial leather straps.

Synthetic leather has the benefit of being waterproof and can be dry-cleaned. It is softer and lighter than real animal leather and it is UV resistant. It is biodegradable and animal cruelty free ('Polyurethane leather: Is synthetic better?', 2015).

Artificial leather, in this case, is made of polyvinyl chloride (PVC) by using additives that will improve its properties and make this material applicable to typical uses. The material has to go through thermal decomposition resulting in ethylene dichloride (EDC), which is converted to vinyl chloride (VCM). It is at this point when the additives are placed.

PVC suspension polymerisation results in a material which is protected from damaging heat, UV light and thermal degradation. If required, pigments are added in the manufacturing process to give the material a specific colour. After this phase, heat is placed on the material for the additives to sink in, and let to cool (Burns, n.d.).

The subjection system is made up of Velcro straps glued to the synthetic leather straps. The details can be found in the Unions section (Monoprice, 2017).

8.2.2. Protective layer

D3O is a UK-based company that develops non-Newtonian materials, mainly used in protective equipment ('What is D3O?', 2018). Their materials excel in impact absorption and comfort by incorporating additives on to the raw material, but how does a non-Newtonian fluid work? When a large force is applied to these materials, the sudden application of stress causes the material's molecules to lock and make the material rigid. When the force is removed, the material returns to its initial state (Illustration 27. How D3O works ('What is D3O?', 2018)) ('Non-Newtonian Fluid', 2010), making it a very interesting material for sports applications because it does not limit the user's movements.

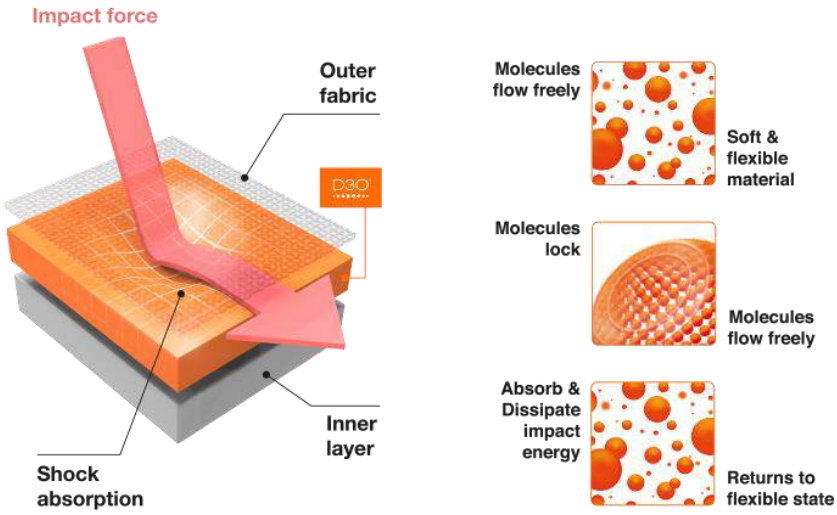


Illustration 27. How D3O works ('What is D3O?', 2018)

These materials are sold directly to brands, and can be sold as raw material or as a processed piece. In this case, the cost of the material has been calculated from a processed part, so the manufacturing process will not be considered.

8.2.3. Unions

To ensemble the final product, some unions will have to be designed. First of all, the external layer will be sewn to the foam separating the protective material from the knee. Here, a pocket will be designed (and sewn) to keep the protective material in place. It will include a Velcro strap to keep it shut.

The subjection Velcro straps will be riveted to the external layer and will surround this material. The other side of the Velcro will be glued to the external layer using a silyl-modified polyethers (MS polymers) ('Adhesives for Polyurethane', 2014; 'How to bond polyurethane', 2016; 'Modified Epoxy and MS Polymer Adhesives', 2016; 'MS 55 Polymer', 2018).

9

FORMAL DESIGN

9. Formal design

9.1. Formal design

The final design of the knee pad has been previously explained. In this chapter, the final drawings are developed. These can be found in the annexes.

9.2. Visual identity

9.2.1. Brand name

A brainstorming session for the brand's name took place. This brand should be related to sports, to activity, to speed, and to youth. For this reason, the most interesting names that came up were movement onomatopoeias (whoosh, zoom, swish…). Eventually, the chosen name was Dash.

According to the online Cambridge Dictionary, "dash" is the action of moving quickly. It is also related to the verb of hitting something ('Dash', 2018), linking the word of speed to impact, which is essentially related to protective equipment.

9.2.2. Colour

According to the brand values, the most coherent colour for the Dash brand is orange. This colour represents playfulness, friendliness and vitality (Ellis, 2017). According to another source, orange can also be linked to invigoration and standing out; it is similar to the passionate red, but friendlier (Gains, n.d.; Morr, 2016). Orange is often associated with excitement, warmth and creativity, as well as cheerfulness (Gross, n.d.; Lindeman, 2017; 'The Hidden Meanings Behind Famous Logo Colors', 2018). Coincidentally, orange is also D3O's brand colour, the protective material brand. This fact makes it easier to combine brands and materials.

Illustration 28. Pantone orange options

From the wide variety of orange tones from Pantone's website ('Pantone', 2018), some were chosen as possible brand colours (Illustration 28. Pantone orange options). The chosen tone for this application is Vibrant Orange (16-1364 TPX), because it is the most cheerful and vibrant of the selection, representing the brand values well.

9.2.3. Typography

For the typography, again, based on the brand's values, 12 options were selected. These were chosen based on their geometry: either they are light typographies, evoking a feeling of a lightweight product, or more decorative fonts that look youthful, fast and bold.

Table 37. Typographies

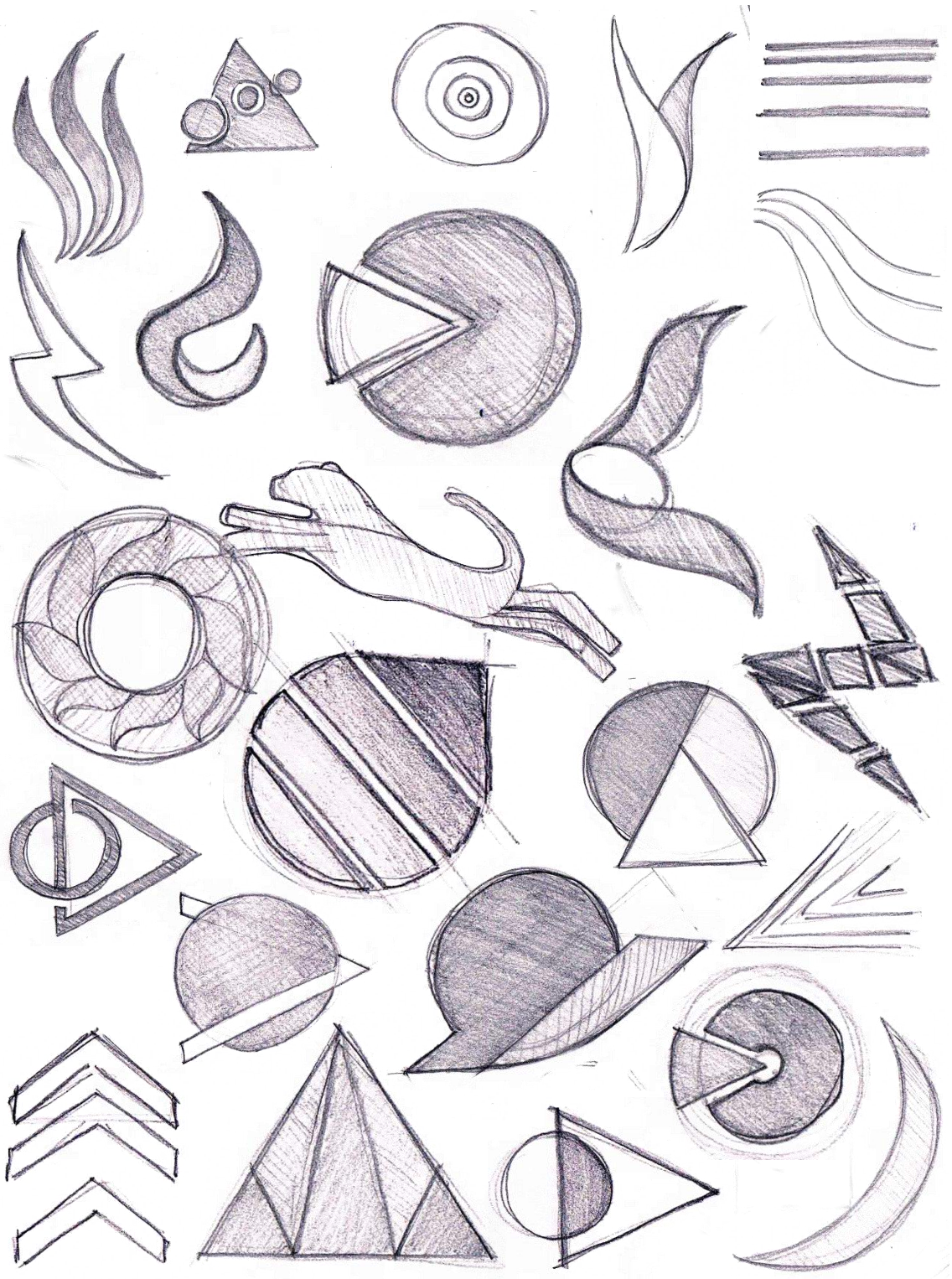
DASH	DASH	DASH	DASH
Adequate	Avignon NF	Avenger	Beast Machines
DASH	DASH	DASH	DASH
Arual	Bahnhof Black	Blockhead	BeetleJ
DASH	DASH	DASH	DASH
Ashby Light	Astro 867	Astrolyte	Autobahn

The final chosen typography is Blockhead, which is a very bold font. It gives a feeling of security, even though it feels quite heavy. The light bolt represents speed and excellent performance. As can be seen in the following tests, although it can depend on screen resolution, the optimal minimal size for this font is 12 px.

DASH	8 px
DASH	9 px
DASH	10 px
DASH	11 px
DASH	12 px
DASH	13 px
DASH	14 px
DASH	15 px

9.2.4. Symbol and logo

After some symbol brainstorming exploring different possibilities representing the brand's values, one was chosen. It is a combination of a triangle and a circle, representing improvement and speed, and a skate's wheel, respectively. The triangle points to the right, as an arrow pushing forward, while the circle represents a safe space, or defense ('What logo shapes mean, part 1: The circle', 2018).



Applying the chosen orange on the chosen symbol and displaying an option in black, the following options are created (Illustration 29. Symbol variants in orange and Illustration 30. Symbol variants in black).

Illustration 29. Symbol variants in orange

Illustration 30. Symbol variants in black

The final logo combines all of the previous phases into one image.

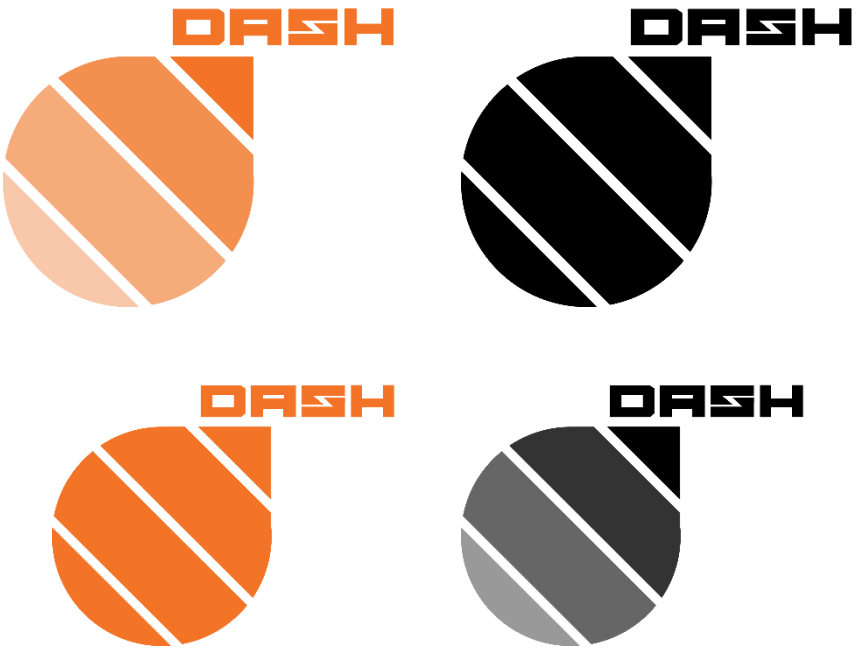


Illustration 31. Final logo

10 BUDGET

10. Budget

This chapter covers the product price. The costs presented are approximate, based on various websites and datasheets with reliable information. These costs are established considering that only one set of knee pads would be manufactured, and these would, of course, be reduced for long series.

10.1. Product budget

Table 38. Product budget

COMPONENTS	AMOUNT	RAW MATERIAL	MANUFACTURING	ASSEMBLY	TOTAL COST
Electronic components					
SEN-13944 (9DoF sensor stick)	2	12.84 €		1.28 €	28.25 €
LTT-SLPA-20K (fabric resistant sensor)	1	21.44 €		2.14 €	23.58 €
SEN-11574 (pulse sensor)	1	21.44 €		2.14 €	23.58 €
LMT70 (temperature sensor)	4	0.70 €		0.07 €	3.08 €
MicroSD breakout board	1	7.50 €		0.75 €	8.25 €
CC2640R2F (microcontroller with Bluetooth)	1	1.95 €		0.20 €	2.15 €
Body components					
Velcro straps	2	2.13 €	0.85 €	0.21 €	6.39 €
Sinthetic leather straps	2	1.03 €	0.41 €	0.10 €	3.09 €
External layer	1	3.52 €		0.35 €	3.87 €
Protective layer	1	8.34 €		0.83 €	9.17 €
Padding	1	3.52 €		0.35 €	3.87 €
TOTAL COST					115.29 €
Structural load	10.00%				11.53 €
Industrial benefit	15.00%				17.29 €
VAT	21.00%				24.21 €
TOTAL PRICE					168.32 €
TOTAL PRICE (Knee pad set)					336.64 €

11

CONCLUSIONS

11. Conclusions

11.1. Conclusions

The success of this master thesis can be measured by comparing the final results to the initial objectives. In the following paragraphs, each of them will be checked.

First of all, a large part of the interest of this project was to analyse the reasons of why users do not wear PPE as often as they should. The results were obtained by an extensive bibliographic research, as well as validating these results with field work. The findings can be considered valid and have been established as the basis of the project.

The initial goal of the design was to create a knee pad that would encourage the use of PPE amongst all skaters, but through the design phase, an innovative niche was found. Wearables are an increasingly popular trend amongst the young, and so electronics were included in the design. This decision has increased the final price of the product drastically, but the target group has also changed. These knee pads are now a training tool for the elite, and therefore the interest they have in improving is larger than the whole skating population.

The final design has focused on materials and functionality and may not have fully responded to aesthetics needs. The protection offered is much higher than that in traditional knee pads, and this has allowed for the rest of material choices to be lighter and more breathable.

The visual identity linked to this product's brand is representative of its values and can be easily identified by its unique font and design. The orange colour is bright and draws attention to itself.

Finally, a prototype was not created due to the complexity of the chosen materials. The most important part of this design is the use of D3O protective materials which are flexible but protect against impacts. As this material cannot be simulated because it is sold directly to brands, a validation prototype was not necessary.

I believe the overall result has been positive and it has been an opportunity to apply the concepts learned throughout the master's programme, as well as establishing those that had been previously learned in the bachelor's degree. I strongly believe that wearables are a very interesting future trend that can offer excellent solutions for products that seem as though they have been designed to their maximum potential.

11.2. Future work

Even though the main objectives have been accomplished, there is more work to in the subject of this thesis. There are two main projects that could be derived from this one: the first would be to design the knee pad in more detail, and the other would be to design other pieces of PPE within the same line of design.

If one were to choose to design this knee pad further, there are some indications to keep in mind. The first one would be to complete the electronic design with new functionalities or with newer components. Other functions could be added while maintaining a low energy consumption. Also, to visualise the results of the measurements of the knee pad, one could design an app, for example. The way of viewing the data can give different types of information, and a combination of the measurements can offer new details on the performance of the skater. Costs should be optimised, as well as detailing the electronic components further.

For the design of other pieces of PPE, one could consider adding electronic components to the different pieces to either distribute energy consumption in different products or to measure unique data from various parts of the body.

Finally, I believe the most interesting aspect of 3D printing for this project is to be able to adapt the product to the user (Gannon, Grossman, & Fitzmaurice, 2015). 3D scanning for a personalised design could lead to more comfort and user satisfaction, and could revolutionise the way in which wearables are designed. This, joined with the use of flexible electronics, which can also be 3D printed (Scott, 2017), would be the ideal solution for this application. Other interesting ideas include the incorporation of cell printing into the design, to create a knee pad that opens and lets the skin breathe when heat or sweat are detected (Tess, 2017).

12

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