A SURVEY AND DESIGN STUDY OF A PROTECTIVE CYCLING TOP WEAR

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Abstract: *Cycling is a popular sport which is preferred by all age groups all around the world. As it is an active sport, it requires special types of clothing to provide comfort to the wearer. In spite being a healthy activity, cycling can result with acute or chronic injuries. In this study, an extensive survey was conducted to the cyclists in order to reveal their preferences of cycling clothes, their requirements, their accidental experiences and safety needs. By considering the survey results, optional designs of a more protective and functional cycling top wear were outlined. In order to avoid from acute injuries which were stated to be in the shoulder and arm areas the most, a para-aramid and spacer/silicon foam supported design was proposed. Also, the visibility was enhanced by the implementation of active lightening on the front and back sides of the clothing.*

Keywords: *cycling top wear, survey study, protective clothing, functional clothing, clothing design.*

1 INTRODUCTION

Recently, there has been an increasing interest in sports because of the desire to be healthier, to relieve stress and to create a lifestyle. Cycling is one of the most popular sports as it appeals to all age groups, promotes general good health, does not require high costs and can be made in all seasons. In addition of being a sport, cycling is a means for a cheap, healthy and a green transportation [1].

Cycling sports can serve to both recreational and professional purposes. The cycling types namely, road cycling, cyclo-cross and mountain biking belong to professional cycling pursuits [1]. They can cover various time intervals and different levels of performance. Therefore, cycling may need different clothes with special properties. Some of the selection parameters of cycling clothes are the price, appearance, size, fit, design, availability and quality [2]. Appearance and fit can be the most important selection parameters for recreational cyclists. But, especially for professional cycling, functional properties and comfort properties are of higher importance [2-4]. Some of the functional and comfort properties expected from cycling clothes are moisture absorbency, moisture management, fast drying, breathability, lightness, stretchability, heat preservation, resistance to sunlight, high visibility etc. [2, 5, 6].

By considering various requirements from the cycling clothes, many studies were done in the literature in particular research areas. Some studies searched the fit of cycling clothes. For example; Vuruskan and Ashdown [7] built half scale dress forms for active body positions of cyclists by capturing 3D body positions using body scanners. In the further study, they produced 3D printed active forms which were equipped with pressure sensors to measure the fit of cycling shorts [3]. Liu et al [4] determined the digital clothing pressure for static condition and dynamic cycling condition by using software and optimized the design of a cycling t-shirt. Compressional properties of compressive cycling clothes were also studied in the literature. Leoz-Abaurrea and Aguado-Jimenez [8] investigated the effect of upper body compression garments on the cardiovascular and thermoregulatory strain of cyclists those cycled in hot environment. Brighenti et al [9] compared the performance effect of a new type of whole body compression garment with ordinary summer cycling cloth in hot climate (32°C). Hintzy et al [10] studied the effects of thigh compression shorts on muscle activity and soft tissue vibration during cycling. Another study field on cycling clothes was the visibility as it could provide protection against cycling accidents. Lahrmann et al [11] made an extensive study in which the effect of bright colored cycling wear on the number of cycling accidents was searched. Lee [12] designed a cycling jacket incorporating solar powered LED (light emitting diodes) sensor lights in order to improve visibility. Koo and Huang [13] tested different configurations of flashing LEDs on cycling clothes to the psychological perception of drivers. Kgatuke et al [14] developed a cycling jacket integrated with LEDs. As smart solutions

to cycling clothes; Paiva et al [15] designed and produced a smart cycling cloth that was able to measure the heart beats of cyclists by means of different materials such as textile and silicon based electrodes. Qiu and Hu [16] proposed and defined the design of a smart cycling top wear that could measure the heart rate, body temperature and moisture of the cyclist by implementing electronic devices to the clothing.

In addition to these researches, there are rare other studies on cycling clothes. As an example, Oglakcıoglu et al [6] investigated the thermal comfort properties of sewn parts of cycling clothes. Teyeme et al [2] searched the pains/injuries of 94 cyclists, which occurred during or after cycling. Vuruskan [17] conducted a cross-national survey study for cycling clothes in which 25 cyclists from Turkey and 25 cyclists from United States were included. In the survey, customers' perspectives on fit and customization were questioned. Teyeme et al [18] organized some wear trials for 4 kinds of cycling wear in order to determine their comfort properties. Kwon and Kim [19] developed a cycling top wear with the combination of 3 fabrics in order to response different sweating rates and compression needs. Also, there are other studies in the literature; conducted to evaluate the comfort properties of knitted fabrics/garments those could be useful for the design of cycling clothes. For example, Suganthi and Senthilkumar [20] examined the moisture management properties of 7 bilayer knitted fabrics composed of different raw materials. Ozkan and Kaplangiray [21] investigated the thermal comfort of 7 knitted fabrics that could be used for athletes' wear. Abreu et al [22] determined the thermal comfort properties of 3 knitted shirts that were suitable for sportswear. Wong and Yeung [23] organized wear trials for 8 knitted sportswear in order to evaluate their comfort properties.

The aim of this study was to create a design idea of a more functional and protective cycling clothing, by considering the user behaviours, experiences and requirements. For this purpose, firstly, an extensive survey was conducted to 500 cyclists in order to collect required information related to their current cycling clothes. In addition, information was collected about their accidental experiences in order to add protective segments on the clothing.

This study differs from the literature by collecting detailed information on cycling clothes about seam problems, visibility preferences, model preferences, comfort requirements and accidental issues and, as all this information was used to create smart solutions for cyclists.

2 MATERIALS AND METHODS

The survey containing 38 questions/statements were constructed according to an 8-step process [24]. According to this methodology, firstly, it was determined what the new information would be obtained from the survey. Then the most appropriate survey type and sampling method was determined. In the next steps, useful questions were constructed and conducted to cyclists via a plan. Then the data was analyzed and presented as tables, figures and mean values. Both the questions and data were controlled several times to avoid from errors.

The final survey form can be found in the Appendix. In the survey, information about the usage behaviors, model preferences, protection and visibility requirements, seam problems and accident experiences were collected in addition to some demographical information.

The survey was firstly tested on a small cyclist group to get feedbacks about the understandability of the questions. After revisions, the last version of the survey was conducted to cyclists utilizing Google Documents, between the dates of June-December 2019. Convenience sampling method was used as it was the least expensive and time consuming method [25]. According to the literature [26, 27], at least 384 participants should be taken where the target population is higher than 10 million. Therefore, in this study, data collection was completed when the total number of respondents reached 500 cyclists. All of the questions were answered by the respondents. The survey was conducted to cyclists in Turkey, including all geographical regions.

In the survey; Likert scale questions (in matrix form), multiple choice questions, Yes/No type questions and open-ended questions were used. Frequency values, means and plots of responses were compared to evaluate the results.

Table 1 Design methodology of cycling top wear

Requirements	Design properties	Materials and fabrication methods
Protection Functionality Usability Maintenance Wearability	Higher visibility function	LED application, colour selection
	Impact protection	Silicon and spacer paddings
	Protection against fall	High mechanical property raw materials
	Thermal and wet comfort	Use of meshed fabrics
	Form fitting	Use of elastane containing fabric
	Seam properties	Use of gusset to eliminate armpit seam
	Easy maintain	Detachable LEDs

For the clothing design, a user-centered approach was adopted for this work [28, 29]. As the design methodology, first 3 steps of the clothing design and development framework that was employed by Rajamanicham, Park and Jayaraman was utilized [30]. For this purpose, firstly, the requirements of our target group were detected by the aforementioned survey study. Then the design properties were formed. At the next step, suitable materials were selected. Details of the adapted design methodology for cycling wear design are summarized in Table 1. By using these principles, 2D flats were created containing alternatives. The cycling clothes were designed by using Designer 9 (Gerber, Artworks Expert). Patchwork design [31] of 4 kinds of fabrics was performed, including the usage of elastane containing polyester fabric, aramid fabric, meshed fabric and supportive spacer fabric, in order to enhance protection and comfort properties of the final design.

3 RESULTS AND CONCLUSIONS

3.1 Demographics and cycling behaviours

Age and gender information of respondents were taken as demographics. The age range of the respondents was 16-65 years old (mean: 34.5, st. dev.: 11.3) (Figure 1a).

The study covered a broad range of ages from 16 to 65. Therefore, the standard deviation was high. 87% of the respondents were male where 13% of respondents were female (Figure 1b). Also, 53% of respondents were licensed cyclists.

Cycling behaviours of respondents are given in Figure 2. According to Figure 2a, respondents used at least one of the 5 bicycle types. At least 30 respondents were taken from each bicycle types. 40% of respondents had been cycling for 7 years or more (Figure 2b). They trained cycling for different time intervals, weekly (Figure 2c). 71% of respondents cycled 2-4 h, non-stopping (Figure 2d). From all these behavioural information, it can be concluded that, respondents were well experienced on cycling.

3.2 Accidents related to cycling

Cycling injuries can be classified into 3 types, namely; traumatic, bicycle contact and overuse (chronic) injuries [32]. Traumatic injuries can be sourced from crashes with other vehicles or bicycles, from potholes, rocks, dogs, operator errors or by mechanical reasons [33]. In this study, traumatic injuries had been explored to reveal if any protection could be provided by altering cycling clothes' design and materials.

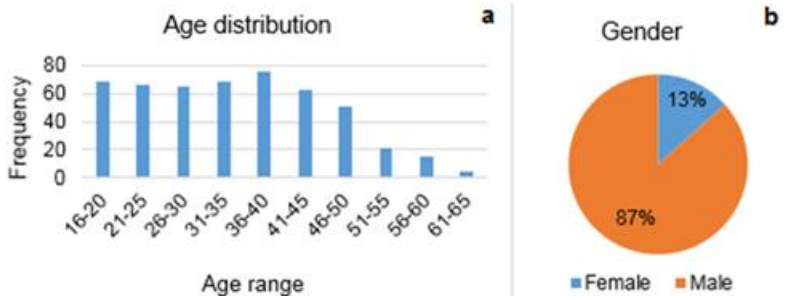

Figure 1 Demographics of respondents

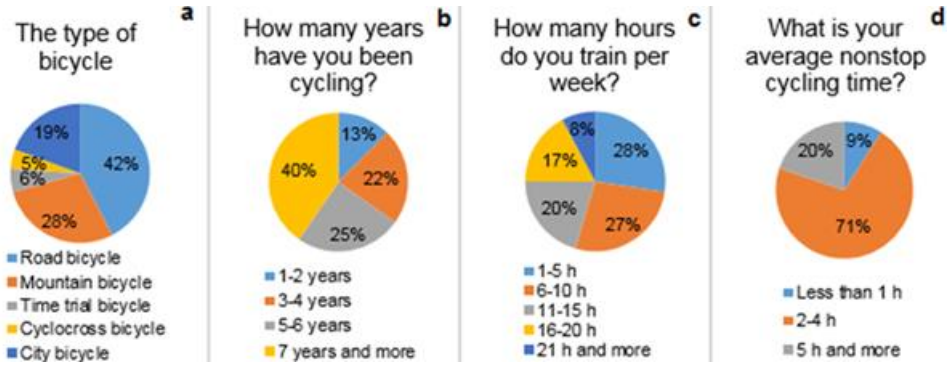

Figure 2 Cycling behaviours of respondents

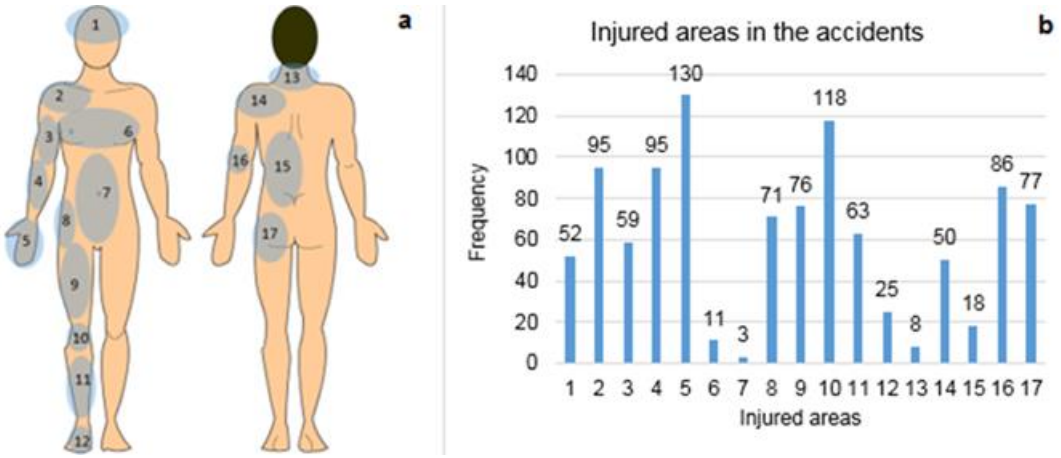

Figure 3 Injury areas of cyclists

According to the results, 59% of respondents stated that they experienced accidents during cycling.

The injured areas of the body were marked in Figure 3a.

The areas such as 2, 3, 4, 5, 15, 16 and 17 also covered “y” axis symmetry of the body. In Figure 3b, frequencies of the injured areas are given. According to results, most injured area was the hands area (26% of respondents) and it was followed by knees area (23.6%). Also almost 20% of the respondents were injured in the shoulders and lower arms area. The total number of upper arm (3), lower arm (4) and elbow (16) injuries was 240. The least injured areas were abdominals, chests and necks.

3.3 Protection, visuality and comfort related requirements from cycling clothes

Respondents mostly cycled in the summer season and under intense sunlight (Figure 4a). Nevertheless, 458 of them at least rarely cycled in the dark weather (Likert mean: 3.2). Also, 93% of respondents stated that they needed high visibility in the dark (Figure 4b). 464 cyclists increased their visibility by using bicycle lights and also 457 of them enhanced the visibility by using clothing (Figure 4c). Among the clothing visibility enhancements, using reflective fabrics was the most employed method (Figure 4d). Higher visibility can protect the cyclists from accidents; therefore, the safety of the cyclists can be enhanced [11, 34-36].

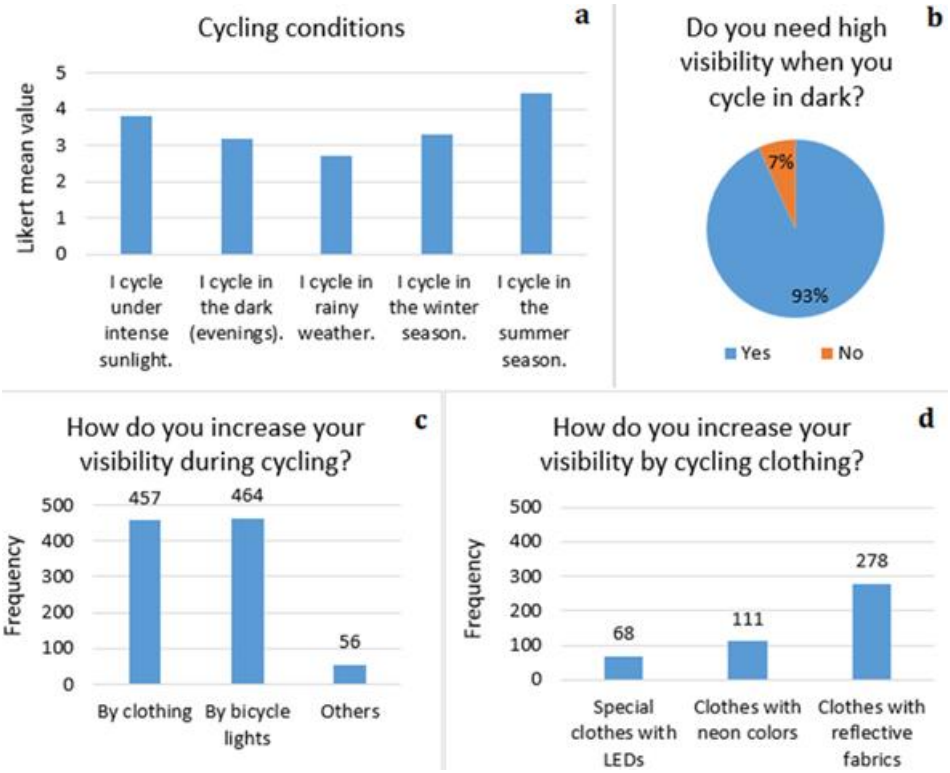

Figure 4 Visuality of cycling clothes

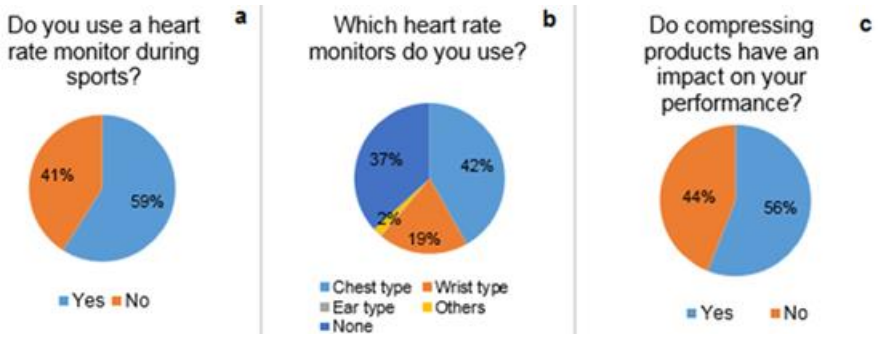

Figure 5 Functional options in cycling

Figure 6 Comfort needs of cyclists

59% of respondents used heart rate sensors during cycling (Figure 5a). Mostly, chest type sensors were used by respondents (Figure 5b). Also, 56% of respondents thought that compressing products could impact their performance (Figure 5c).

Comfort related requirements from cycling clothes were also questioned in the survey and the results are shown in Figure 6. Likert mean values for being thin, lightweight, air permeable, moisture permeable, fast drying and thermal insulator were higher than 4.4. The mostly desired comfort property of cycling clothing was drying fast (Likert mean: 4.8). It was followed by being lightweight, air permeable and moisture permeable at high levels (Likert mean: 4.7). In addition, comfort approaches of female and male cyclists were similar. The literature also supports the needs of moisture/heat transfer properties and lightweight of cycling clothes [37]. In addition, it was determined in a survey based study that the most common discomfort problems of cyclists were related to moisture and thermal discomfort sensation in their current clothes [2].

3.4 Seam problems of cycling clothes

Most of the respondents (75%) stated that they did not have seam problems (Figure 7a). The rest of the respondents experienced marks on their bodies along the seam lines, the most (Likert mean: 2.5). The seam related problems were detected in the armpit area on top wear and in crotch area on bottom wear (Figures 7c, 7d).

3.5 Cycling clothes preferences and maintenance behaviors

Cycling clothes preferences of respondents are given in Figure 8. According to Figure 8a, 59% of respondents wore M or L size clothes. 69% of respondents preferred fitted models instead of regular models (Figure 8b). 87% of respondents preferred cycling clothes with 3 or more pockets (Figure 8c). 73% of respondents preferred raglan armhole and 74% of respondents preferred full length zipper on the top wear (Figures 8d, 8f). Raglan armhole increases the movement range of shoulder and zipper provides easy take off of the clothes [37]. Collar preferences changed according to model (Figure 8e). Collar preferences may be up to the fashion. As the bottom clothes, almost half of the respondents preferred tights with straps while the rest half preferred tights without straps (Figure 8g). In Figure 8h, sleeve length preferences of respondents in both summer and winter time are presented. According to the figure, most of the respondents preferred short sleeve in summer time and long sleeve in winter time, rather than the other sleeve types such as sleeveless, elbow and ¾ sleeve lengths.

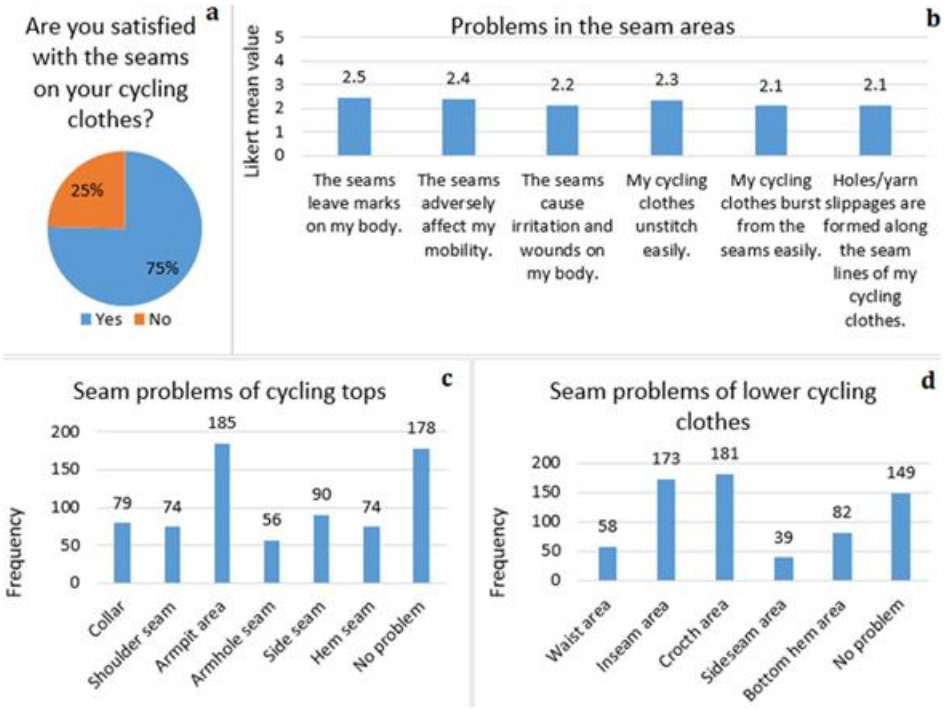

Figure 7 Seam related problems

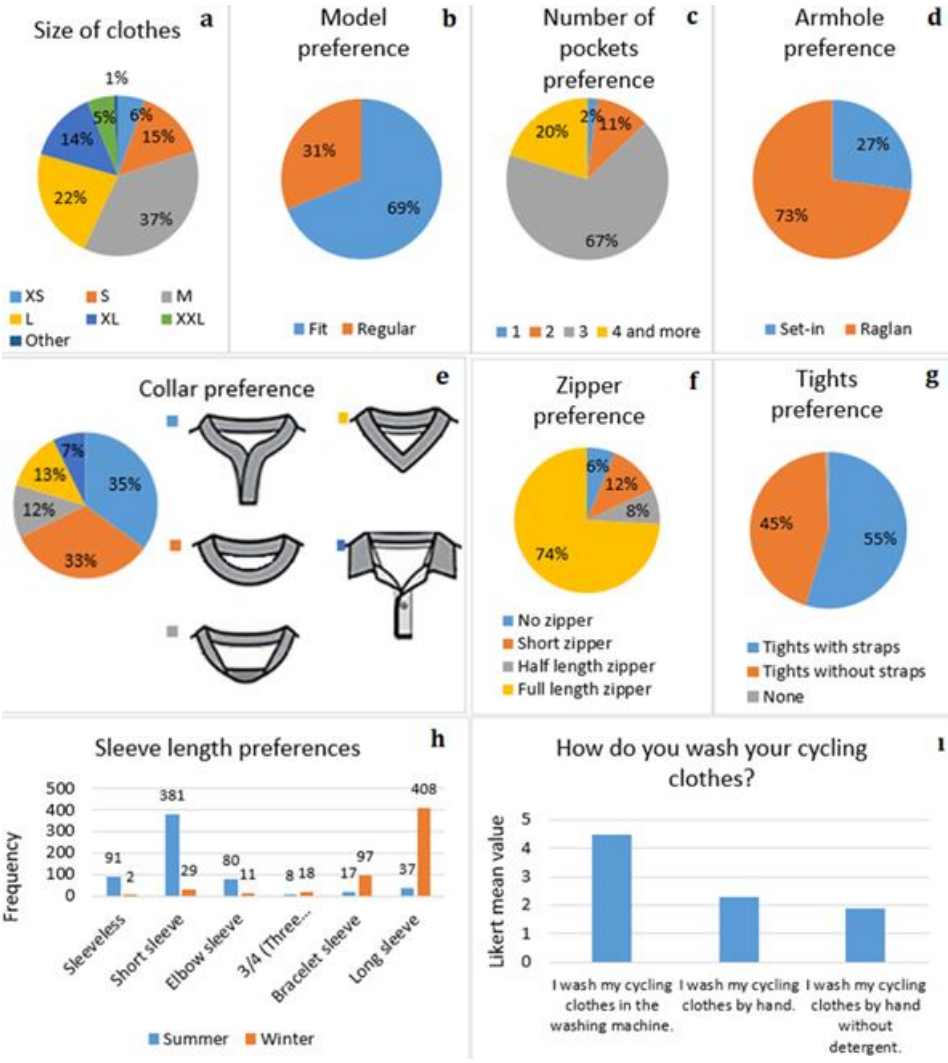

Figure 8 Cycling clothes preferences and maintenance

4 DISCUSSION AND CYCLING GARMENT DESIGN

Images of some commercial cycling top wears are given in Figure 9. By considering both the commercial products and survey results, a basic cycling top wear was designed as given in Figure 10. It is planned to be made of elastane containing knitted fabric. It is designed to be fit cut; it has 3 pockets, raglan armhole and full length zipper, according to clothing preferences of survey participants.

Figure 9 Images of commercial cycling wears. Products of a) Decathlon [41], b) Rapha [42], c) POC [43], d) Pedla [44]

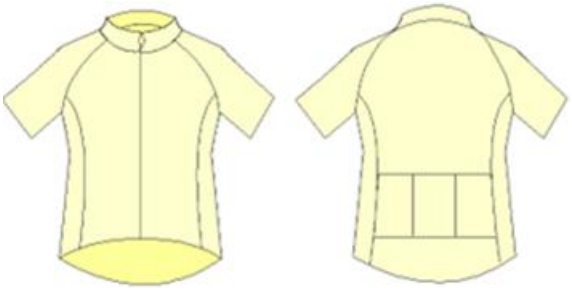

Figure 10 A classical one color cycling top wear (jersey)

Only in Turkey in the year of 2018, 8514 traffic accidents included bicycles and 125 cyclists died according to official statistics [38]. Therefore, in this study, information about both injuries in accidents and visibility preferences were collected to develop a clothing design that would provide extra protection to the wearer.

According to survey results, shoulders, elbows and arm area were the most injured areas that could be protected by the top wear. In order to provide protection to these areas, the outer side of the sleeve was designed to be supported with a spacer fabric and aramid fabric combination. As aramid fabric has high strength [39], it will be durable against cutting when the arm of the cyclist contact with the road in case of fall. So the exposure of the skin to the road will be inhibited and it is expected to prevent wounds. Short sleeve was not preferred because of the aramid support along the arm.

Also, the elbow and shoulder parts of the clothing was planned to be supported with additional knitted spacer pads in order to absorb the impact in case of fall.

For the ideal protection, weft knitted spacer fabrics with different thicknesses can be tested to determine their damping capability of impact [40]. Spacer fabrics can provide protection while maintaining lightweight.

Also, impact absorbing pads may be produced from silicon containing cushions, which have currently use in cycling shorts as given in Figure 11.

Figure 11 Silicone foam containing cycling short pad vs spacer fabric for soft padding: a) silicon sponge [45], b) spacer fabrics [46]

For the sleeve construction, different designs were developed and 5 of them are given in Figure 12.

In these designs, the coverage and patterns of aramid and spacer pads are altered. The designs of a, b and d were eliminated because of the voluminous structure of spacer pads. Those designs could result with reduced mobility and sewing problems in the curvy armhole places. Figure 12e was preferred as the final sleeve design as the spacer pads were placed in the target sides as shoulder and elbow. In addition, it was more advantageous by having less amount of expensive aramid fabric, when compared to design in Figure 12c.

To have an idea about the compatibility of knitted polyester fabric and aramid fabric, a sewing trial was performed. For this purpose, a knitted aramid fabric was sewn with a single-jersey polyester fabric by using 5 yarn overlock stitch as shown in Figure 13.

Two fabrics (aramid and polyester knitted fabrics) were found to be compatible in terms of sewability and stretching, also there were no visual problems along the seamline. Here, polyester was trialed because it is used in commercial cycling clothes, extensively. And the reason to support the polyester fabric with aramid was that the aramid fabrics had high mechanical properties. In the further studies, fabrics with different raw materials can be tested as alternatives. By considering these results and sketches, the final cycling top wear was designed as in Figure 14.

In the design, to eliminate the seam problems in the armpit area, a diamond gusset may be added as shown in top left side of Figure 14. Also, this gusset may be manufactured from meshed fabric in order to enhance the heat and moisture transfer from the armpit. The design can be used for cycling in dry weathers of spring or autumn seasons. Also, it can be used as an inner layer for winter season, too. For the summer season, the sleeve can be made of an elastane containing meshed fabric in order to improve the moisture and air permeability, to maintain both the protection and comfort at the same time (Figure 15).

The visibility of top wear was enhanced by using contrast and vivid neon colors and active LED supports. Most of the respondents stated that they did not use LEDs on their cycling clothes. Literature showed that the usage of flashing LEDS can improve the recognition of cyclist in the dark. Koo and Huang's study [13] suggested to put the flashing LEDs on the lower garment at hip, knee and ankle. But also, the LED configuration on the top wear took good scores. Therefore, for this study, LEDs' configurations were designed as given in Figure 14. An alternative LED configuration can be formed as in Figure 16. A LED array was planned to be placed in the front and back torso as given in figures. Also, a small pocket was added to carry the battery. Kgatuke et al [14] made a design by inserting LEDs in the weaving process. According to our survey results, most of the cyclists wash their clothes in washing machine, so, in this study, detachable LED arrays were proposed in the design to plug off easily before washing. The attachment of LED arrays may be enabled with Velcro or snap fasteners. A variant of this cloth might be designed with integrated gloves.

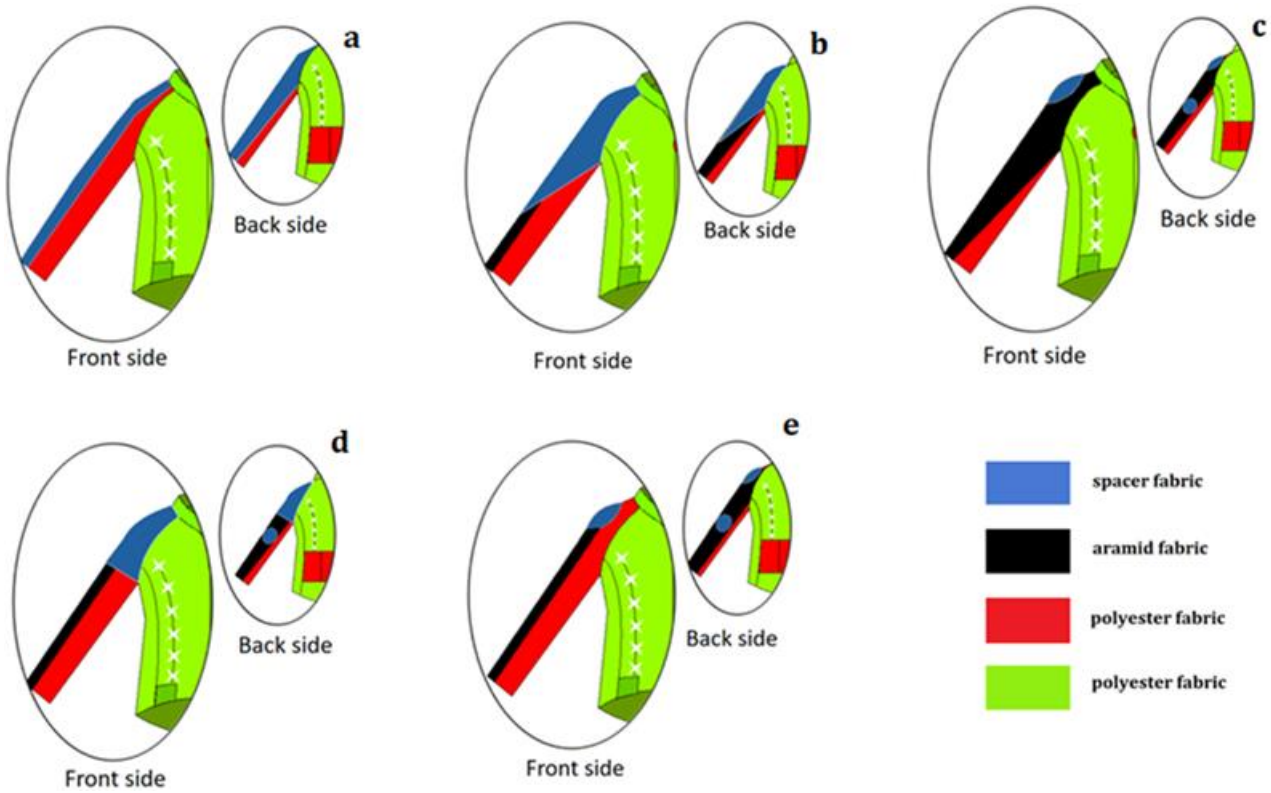

Figure 12 Different design alternatives for sleeve

Figure 13 Sewing trial of aramid fabric with polyester fabric

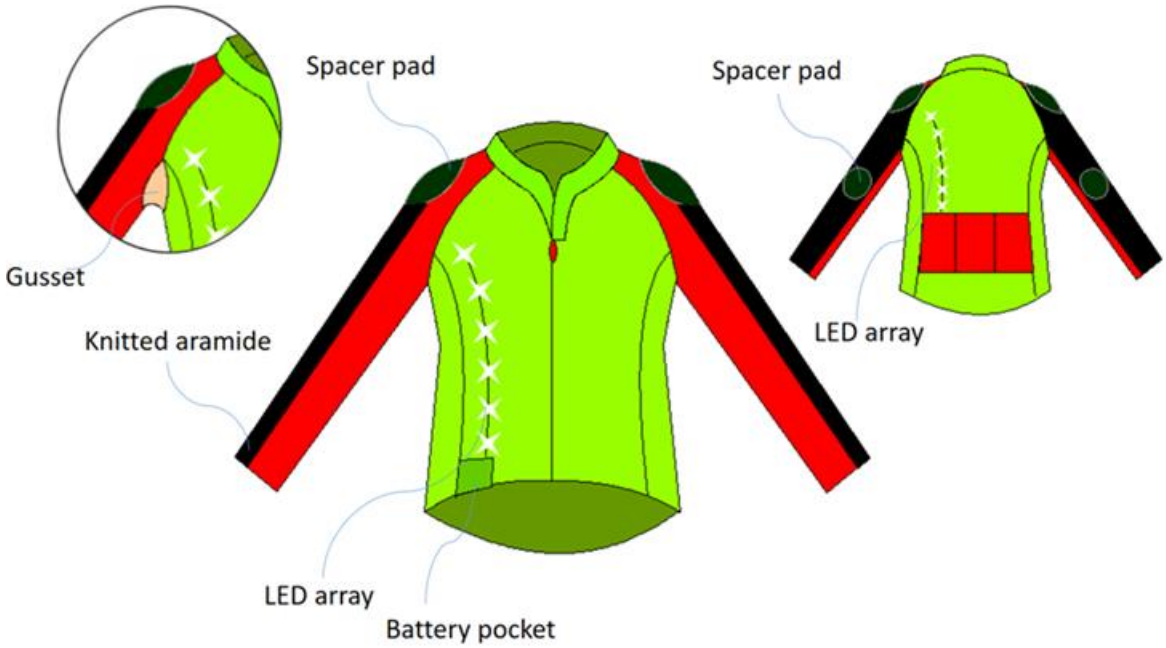

Figure 14 Design of a LED containing cycling jersey supported via aramid fabric and spacer pads

Figure 15 Design of the proposed cycling jersey with mesh sleeves for summer season

Figure 16 Design of the proposed cycling jersey with alternative LED arrangement

Additional important implications of this study can be summarized as below:

- More than half of the cyclists stated that they used heart rate sensors. 42% of the respondents used chest type heart rate sensors that should have high contact with the body. As an alternative, ear type heart rate sensors may be integrated to the cycling top wear as the authors realized for sailing garments in previous studies [47]. It can provide wear comfort and extra mobility to the cyclists.
- Cyclists have high expectations from their clothes in terms of physiological comfort. Moisture management finishing may enhance the comfort properties of cycling jerseys.
- There were no serious problems about the seams of cycling clothes. But some cyclists stated that, their seams left marks on their bodies. It is related to fit cut of cycling clothes those contact with body tightly. This problem can be solved by replacing sewn seams with taped seams. Taped seams provide a flat and smooth hand to the seam [48]. This can be applied along the straight side seams or lowly curved seams as it is harder to apply welding tapes in highly curved areas such as crotch and armpit seams.

5 CONCLUSION

Within the context of this study, an extensive survey research was performed to collect essential information to create the design idea of a more functional and protective cycling cloth. By considering survey results and literature search, 2D flats of protective cycling top wears were created as proposals.

For the design development process, patchwork design approach was found advantageous in obtaining protective clothing that also exhibited high level of comfort. In the designs, 4 types of textile structures, namely elastane containing knitted polyester fabric, knitted aramid fabric, meshed polyester fabric and spacer fabrics, were combined together by considering their general properties. In the further studies, material alternatives are planned to be tested for the selection of the best combinations.

In addition, detachable LED configurations were found suitable for visibility enhancement and easy maintaining.

In the further studies, the cycling cloth designs can be realized and wear trials can be done for long term studies. This study is expected to help the cycling clothes producers by revealing real problems and requirements of cyclists from their clothes. Also, it is expected to sketch a new perspective for the design of protective cycling clothes.

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7 APPENDIX

Survey Form **DESIGN OF A CYCLING TOPWEAR**

Age:
Gender:

What type of bicycle do you use?
- ☐ Road bicycle
- ☐ Mountain bicycle
- ☐ Time trial bicycle
- ☐ Cyclocross bicycle
- ☐ City bicycle

How many years have you been cycling?
- ☐ 1-2 years
- ☐ 3-4 years
- ☐ 5-6 years
- ☐ 7 years and more

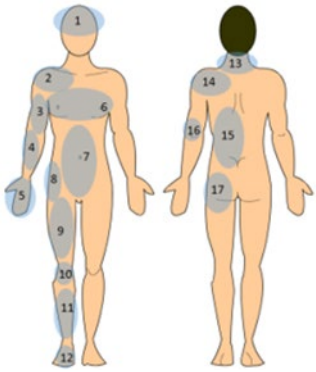
How many hours do you train per week?
- ☐ 1-5 h
- ☐ 6-10 h
- ☐ 11-15 h
- ☐ 16-20 h
- ☐ 21 h and more

What is your average nonstop cycling time?
- ☐ Less than 1 h
- ☐ 2-4 h
- ☐ 5 h and more

Are you a licensed cyclist?
- ☐ Yes
- ☐ No

Did you experience any accidents during cycling?
- ☐ Yes
- ☐ No

Please indicate the injured areas in the accidents?
Injured area……



How long do you wear your cycling clothes?
- ☐ 1 year
- ☐ 2-3 years
- ☐ 4 years and more
- ☐ Until it becomes unusable due to accidents, etc.

What is your size of clothing?
- ☐ XS
- ☐ S
- ☐ M
- ☐ L
- ☐ XL
- ☐ XXL
- ☐ Other

What is your model preference for your cycling clothes?
- ☐ Fit
- ☐ Regular

How many pockets do you prefer on your cycling clothes?
- ☐ 1
- ☐ 2
- ☐ 3
- ☐ 4 and more

Do you need high visibility when you cycle in dark?
- ☐ Yes
- ☐ No

What are the materials you use to increase visibility?
- ☐ Special clothes with LEDs
- ☐ Clothes with neon colors
- ☐ Clothes with reflective fabrics
- ☐ Bicycle lights
- ☐ Others

Do you use a heart rate monitor during sports?
- ☐ Yes
- ☐ No

Which type of heart rate monitor do you use?
- ☐ Chest type
- ☐ Wrist type
- ☐ Ear type
- ☐ Others
- ☐ None

Do you think that compressing products have an impact on your performance?
- ☐ Yes
- ☐ No

Are you satisfied with the stitches on your cycling clothes?
- ☐ Yes
- ☐ No

Please indicate your agreement degree to the statements below.

Properties of cycling clothes	Strongly agree (5)	Agree (4)	Undecided (3)	Disagree (2)	Strongly disagree (1)
My cycling clothes should be thin					
My cycling clothes should be lightweight					
My cycling clothes should dry fast					
The thermal insulation of my cycling clothes should be good					
The air permeability of my cycling clothes should be high					
The moisture permeability of my cycling clothes should be high					

How do you wash your cycling clothes?

Washing behaviour	Always (5)	Often (4)	Sometimes (3)	Rarely (2)	Never (1)
I wash my cycling clothes in the washing machine					
I wash my cycling clothes by hand					
I wash my cycling clothes by hand without detergent					

Please indicate the weather conditions you cycle.

Weather conditions	Always (5)	Often (4)	Sometimes (3)	Rarely (2)	Never (1)
I cycle under intense sunlight.					
I cycle in the dark (evenings).					
I cycle in rainy weather.					
I cycle in the winter season.					
I cycle in the summer season.					

Please indicate the problems you experience with the sewn places of your cycling clothes.

Sewing problems	Always	Often	Sometimes	Rarely	Never
The seams leave marks on my body					
The seams adversely affect my mobility					
The seams cause irritation and wounds on my body					
My cycling clothes unstitch easily					
My cycling clothes burst from the seams easily					
Holes/yarn slippages are formed along the seam lines of my cycling clothes					

Indicate the areas where you have the most seam problems with your cycling top clothes.

- ☐ Collar
- ☐ Shoulder seam
- ☐ Armpit area
- ☐ Armhole seam
- ☐ Side seam
- ☐ Hem seam
- ☐ No problem

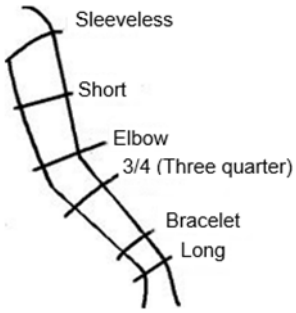
Indicate the areas where we have the most seam problems with your lower cycling clothes.

- ☐ Waist area
- ☐ Inseam area
- ☐ Crotch area
- ☐ Sideseam area
- ☐ Bottom hem area
- ☐ No problem

Which cycling tights do you prefer?

☐ Tights with straps

☐ Tights without straps



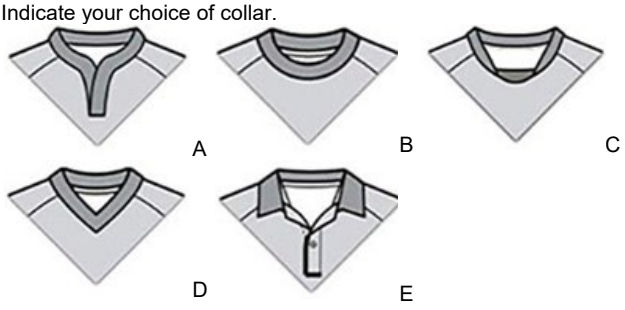
Which sleeve length do you prefer in the SUMMER season?

- ☐ Sleeveless
- ☐ Short sleeve
- ☐ Elbow sleeve
- ☐ 3/4 (Three quarter) sleeve
- ☐ Bracelet sleeve
- ☐ Long sleeve

Which sleeve length do you prefer in the WINTER season?

- ☐ Sleeveless
- ☐ Short sleeve
- ☐ Elbow sleeve
- ☐ 3/4 (Three quarter) sleeve
- ☐ Bracelet sleeve
- ☐ Long sleeve

Indicate your choice of collar.



Indicate your choice of armhole.

- ☐ Set-in
- ☐ Raglan

Indicate your choice of zipper.

- ☐ No zipper
- ☐ Short zipper
- ☐ Half-length zipper
- ☐ Full-length zipper