Wool garments for exercise in cold climate

And why this is to prefer

Martine Frostad Engeseth
Department of Product Design
Norwegian University of Science and Technology

ABSTRACT

Wool is a natural fibre with a unique combination of properties that can be exploited in woollen garments. These properties can particularly benefit the wearer of the garment during exercise. The qualities of the wool fibre and how these can solve the challenges that the human body encounters during exercise in cold climate are discussed in this article. The wool fibre has been investigated through a literature review, and is thoroughly presented focusing on the qualities that benefit the human body. A study that explores the findings from the literature review was conducted in relation to writing this article, and is included at the end of the article. The study involved nine participants testing wool gloves for alpine touring. The results from this experiment are presented, showing the links between the qualities of the wool fibre and the challenges of exercise in low temperatures in practice. Consequently, knowledge of how and why wool is a suitable material to choose when designing garments for exercise in cold climate is established.

KEYWORDS: Wool, fibre qualities, exercise, cold climate, garments

1. INTRODUCTION

The usage of wool goes way back and holds many traditions. Humans have always needed clothing to protect their body from cold and hot weather. In low temperatures woollen textiles have played a substantial role of applying comfortable working conditions in the earlier days, and now also keeping the user warm under training and recreation activities in cold weather. Wool is a natural protein fibre that comes from mainly sheep, but also from animals such as llamas and goats. The wool fibre has several qualities that can be exploited further and into new functional garments. However, it is the composition of the qualities that is unique. No man made fibre can compete with the wool fibre in providing all these preferable qualities in the same fibre. Wool is breathable, flame retardant, quiet under movement, odour resistant and naturally antibacterial. The wool fibre also has the ability to wick moisture away from the skin so that the user stays dry. All these properties qualify wool as a high-performance fibre.

Wool from sheep has been used as a textile fibre for thousands of years [2]. Today, the various breeds of modern sheep produce a wide range of wool qualities. These are classified according to fibre length and diameter, where the finest wool is used for apparel fabrics. The merino breed is the most important in producing fine wools, typically in the range of 17 to 25 µm. The merino breed, originated in Spain, has been developed to produce wool with highly valued properties of fineness, length, lustre, crimp and colour [2].

The intention of this article is to present the qualities of wool as a textile material and discuss how these qualities can meet the users needs under high intensity training in cold climate. Is the wool fibre an ideal material for garments to be worn during exercise in cold climate? The article aims to give a theoretical basis of why this is a fact, and what makes it a fact. First, the wool fibre and qualities of the wool fibre that can be preferable for the human body are presented. Second, the key challenges for the human body during exercise, relevant to training garments, are presented. Then the qualities of wool and challenges garments for exercise encounters are linked and discussed. At the end, a case study investigating the results discussed is presented.

2. METHODS

2.1 Literature Review

Literature review was used to gain theoretical insights, and to ensure thorough understanding of the wool fibre and the human body during exercise in cold climate. It was challenging to find sources that directly linked the topics together, and as a result wool and the human body during exercise had to be investigated in separate searches. Wool is a material that humans have benefited from for decades. This reflects the amount of sources available on the topic. It was therefore necessary to limit down the search and focus on the goal of the article; investigating the wool fibre as a material for garments to be worn during exercise. The timeframe was quite wide because interesting investigations on the wool fibre done many years ago are still relevant as it is a natural fibre, with an unique fibre structure.

Majority of the literature was collected from the Oria portal, provided by the NTNU University Library. Books and articles concerning wool and textiles for sports were further investigated. This included both primary sources with directly descriptions of research by the individual who actually performed the study, as well as secondary sources written by authors that did not directly observe the events described. Keywords being used for searching literature about wool were wool textiles, qualities of wool, natural fibres, etc. These were also combined with keywords like sport garments, high intensity training, and so on, but this gave fewer results. The human factors of high intensity training were therefore investigated in a separate search using keywords like human body, sweat, high intensity training, etc. These searches resulted in detail knowledge about the wool fibre and wool as a material for technical training gear. The article presents the results from the two searches separately and then combines the information to give a clear picture of how the qualities of wool can solve the challenges training clothes for the outdoor encounters.

2.2 Cultural Probe

To link together how the qualities of the wool fibre can solve the challenges one may experience under high intensity training a case study was conducted. The test was laid out as a Cultural Probe. Cultural Probes, also known as diary studies, is a technique that allows the users to self-report. This is appropriate when you need to gather information about users and their activities with minimal influence on their actions. Cultural probes offer a way to extract information from subjects on pre-meditated design questions, as well as stimulate creativity and ideation [13]. Cultural probe was also an appropriate method in the study presented later in this article, because the study involved too many people over a too narrow time span to make it possible to observe everyone. Since the test only had one observer, the author of this article, and the test period was two weeks, it was impossible to observe each user individually. The test aimed to test technical wool gloves during alpine touring to prove the qualities of the wool material during exercise.

Recruiting is a particularly important part of cultural probes. Participants have to use a great amount of their time on the activity, and should therefore be carefully selected based on research goals [14]. The participants of a cultural probe

are often given a kit of materials, dependent on what information one seeks to get. The participants of the glove study were given an individual pair of gloves and an information brochure. The brochure explained the test, and what they should note down and think about at each stages of the experiment. This was a careful briefing of the participants to help them gather the right information. However, it is important not to restrict the information the users gather during an experiment, as this may cause one to miss out on important insights [13].

3. THE QUALITIES OF WOOL

The wool fibre has many qualities that benefit the user of woollen garments. Other fibre textiles may have individual properties that are better than those of wool, however the complex physical and chemical structure of wool gives wool a large range of useful properties that is unique from any other textile fibre [6].

Wool is a natural fibre in the category of animal fibres, or protein fibres. Other examples of protein fibres are cashmere, alpaca and silk. The wool fibre typically comes from sheep but may also come from other animals such as goats and llamas [1]. Wool is the most breathable fabric in the world [1]. This makes it an excellent choice for textiles to be used under training since the body releases fluid in form of sweat that needs to be transported away from the skin to maintain the body temperature. Merino wool used in technical base layer garments are said to be able to regulate the body temperature in all conditions, insulating the body when it is cold and keeping the user cold when it is warm. Wool also has the ability to wick moisture away from the skin so that the user stays dry. Nevertheless it is flame retardant, quiet under movement, odour resistant, non allergenic [6] and naturally antibacterial [1]. The qualities of wool that can be experienced through wearing woollen garments, and which the user can benefit from, will now be presented. How the wool fibre gains these properties through its fibre structure will also be illustrated.

3.1 Protein Group

Wool belongs in the group of proteins known as α-keratins [2]. This is because wool contains protein with a α-helical conformation [6]. A characteristic of these hard keratins is a higher concentration of sulfur than is found in soft keratins, such as those in skin. Wool fibres consist of a complex mixture of approximately 170 different proteins, which is composed of 20 amino acids [2]. The relatively amount of the amino acids in wool vary greatly between sheep breeds and individual animals. This is because wool is a biological composite material in which the various material are not distributed homogeneously, but are concentrated in different regions of the fibre. The epicuticle is the outer layer of the wool fibre, the external surface. It is the epicuticle, and its layer of bound fatty acids, that control the properties of wool, such as friction, handle and wettability [2].

3.2 Fibre Structure

Wool is classified according to fibre length and diameter. Coarse wools, which generally range in diameter from 28 to 45 µm, are mostly used in interior textiles [6]. Fine wool, <25 µm, are used in apparel and the most important source of fine wool is the Merino [6]. This sheep were developed to produce wool of great fineness, desirable length, crimp and colour. Basic merino types include wool qualities from 24,5 µm to 11,5 µm [6].

Raw wool contains around 25-70% of impurities [6]. These impurities are wool grease, suint, dirt and vegetable matter. Wool grease is a mixture of fatty acids and esters, suint consists of potassium salts of fatty acids, plus phosphate, sulphate and nitrogenous compounds [6]. Wool grease, suint and dirt are removed by scouring. Vegetable matter is removed by carbonizing with sulphuric acid. Wool reacts with a much larger range of chemicals than other textile fibres [6]. The chemical qualities of wool is the reason for its many properties. Wool has three main types

of reactive groups, and these are peptide bonds, the side chains of some of the amino acids, and disulfide crosslinks [6]. Because of the reactivity of wool one have been able to develop many industrial processes like in shrink proofing, dying, flame resistance and finishing. The cells of the internal cortex make up almost 90% of the wool fibre and are largely responsible for its mechanical properties [6].

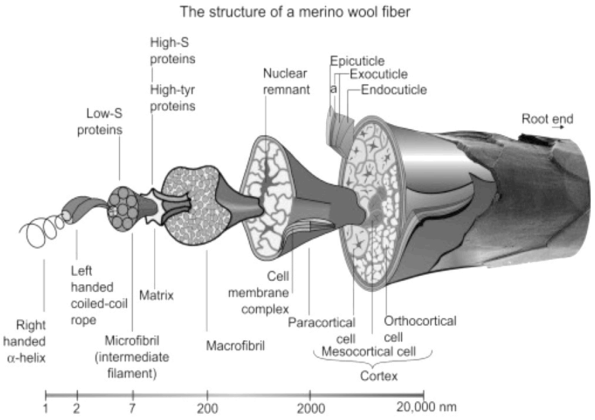

Figure 1: The structure of a merino wool fibre [6].

3.3 What gives the wool its qualities?

Cortical cells composed of highly ordered, crystalline proteins, called intermediate filaments gives the wool its elasticity, resilience and good wrinkle recovery [6]. The ability of wool to absorb a relatively large amount of water compared with other fibres, without feeling wet, comes from the matrix proteins, which are richer in sulfur [6]. Also, matrix proteins are important in the dying process because they are where dyes are located when wool is dyed to equilibrium [6]. Ortho- and paracortical cells differ in a number of ways, but it is these cells that are responsible for the highly desirable crimp in fine wools [6]. The orthocortex is always oriented toward the outside of the crimp curl, which results in two segments twisting around the fibre in phase with the crimp. The fibre crimp is giving wool fabrics bulkiness by preventing fibres from being packed closely together. This bulkiness in the fabric increases the amount of entrapped air, and hence it increases the insulating properties [6].

Cuticle cells, or scales, forms a sheath around the cortex and account for approximately 10% of the fibre mass. The cuticle cells overlap both along and around the circumference of each fibre, and this structure makes the wool fibre unique among textile fibres. This is why wool is able to felt when agitated under moist conditions and the reason for wettability and tactile properties [6]. The thickness of cuticle cells range from 0.3 to 0.5 µm and are approximately 30 µm long and 20 µm wide.

3.4 Odour Sorption

Body odours can be absorbed and trapped within the fibre until laundering because of the complex chemical and physical structure of wool [6]. The various bindings of groups in the peptide side chains also enable wool to bind many toxic gases. During exercise the fibres in wool garments swell to allow odour molecules to diffuse into the structure. When exercise stops the sorbed moisture is evaporated and the fibres contract [6]. The odour molecules however are still trapped in the structure until the garment is washed. In addition to being trapped, odours are also prevented to appear [6]. This is thanks to the moisture absorbing properties of wool removing moisture from the skin and by doing so providing a less favourable environment for bacterial growth on the skin.

3.5 Water Sorption

Wool absorbs or desorbs large amount of water with changes in the surrounding relative humidity. “Regain” is the term used for water sorbed in wool, and is the mass of water expressed as a percentage of dry mass of the fibre [6]. The moisture regain of wool at saturation is around 33%, and this is considerably higher than that of other textiles [6]. Sweat accumulating on the skin causes discomfort for the user, but garments made form hygroscopic material, such as wool, can absorb the moisture

and transport it away from the skin [6]. The ability of wool of absorbing 33% of its mass without feeling wet makes wool garments an excellent moisture buffer during physical activity, keeping the moisture content around a level consistent with wearer comfort [6]. However, the property giving wool an important advantage over other textile fibres when it comes to water absorption it that heat is liberated when wool absorbs water [6]. This is an important quality because it reduces the discomfort a person wearing wool and moving from a dry indoor environment to a cold damp atmosphere outdoors may experience [6]. Wool is multiclimatic, acclimating to the surroundings and acting as a buffer to prevent rapid changes in indoor relative humidity.

The maximum water absorption of wool can be reached at the temperature of 37 degrees Celsius [4]. All natural fibres have a high percentage of cellulose, and therefore the moisture absorption can be high [9]. The high moisture absorption capacity is an advantage when it comes to clothing for the absorption of human sweat [9].
When the wool fibre absorbs moisture, like sweat, the fibres swell and shape, size and so on may change. What is so great about wool in this situation is that the fabric has the ability to regain its original shape after wear.

3.6 UV Protection

Wool serves as an excellent UV protector. This is because the UV-absorbing amino acid residues present in the keratin structure, which also cause photo yellowing [6]. This makes wool sun safe, with a naturally high UV protection compared to cotton and synthetic fibres of similar weight and construction [6].

3.7 Breathability

Breathability is the water vapour transmission properties of the fabric [15]. The type of coating or membrane affects the breathability of the fabric. Test shows that natural fibres have a better breathability than artificial fibres. After sweating 10 to 90 minutes the absolute humidity at the skin surface increased much more quickly and to a significant higher value in clothing with low contents of wool (natural fibre) [5]. The wool had a better ability to transfer the moisture from the inside to the outside, keeping the skin of the user dryer [5]. Wool is the fabric that offers best breathability in the world [1].

3.8 The Flame Retardancy of Wool

Wool is a protein fibre and therefore has nitrogen, which is non-flammable, as part of its chemical composition. This results in the fibre to ignite and burn much less easily [2], and having a high ignition temperature of 570-600 degrees Celsius [6]. The high level of nitrogen causes the wool to have a slow flame spread, and once the initial ignition is extinguished, it ceases to burn. In fact, when the fabric has a large surface mass (above 800g/m2) wool is considered as a non-combustible material [1]. The low concentration of oxygen (25-26%) and high moisture content (15%) are responsible for these properties, and the wool burning slowly and being easy to extinguish [6]. Woollen textiles can ignite, but in most cases they will only smoulder or carbonize rather than burning with flame. The wool will burn to ash, which then cools immediately and can easily be removed from surfaces, including skin [1].

3.9 Measurement of Fineness

Fineness of wool is measured in µ or microns and indicates the softness of the wool. It is the diameter of the fibre that gets measured. Lower amount of microns indicates wool that is most comfortable to skin. Tolerance for coarse wool varies from person to person, but is mostly dependent on fibre diameter. The most comfortable wool is between 17 and 24 µm [3]. Finer fibres naturally give greater comfort. The comfort limit for garments worn next to skin is on the average 28 µm [3]. Many people experience discomfort if the amount of fibres over 28 µm is over 3-4 %.

3.10 Recovery of shape

Wool is superior to other natural fibres when it comes to elastic recovery after deformation, and when it comes to maintaining shape and bulk over long periods of use [6]. Until the development of polyester, wool had the best wrinkling recovery properties of all textiles. Wool still has the advantage over other fibres that wrinkles inserted during wear are easily removed [6]. This is achieved by hanging the garment in a humid atmosphere overnight, under condition where the matrix relaxes and recovery is allowed.

3.11 Fabric Hand of Wool Fabric

Fabric hand means the impressions that arise when a fabric is touched, squeezed, rubbed or otherwise handled [8]. The finishing processes have a reasonable impact on the fabric hand, as they are the last step before the fabric is converted into garments. The temperatures and pressure applied during dry finishing processes influence the retention of a fabric's shape as well as the mechanical and physical properties of woollen yarns and fibres [8]. Finishing processes also affect the drape and fit of a garment to the body.

There are several methods to change the surface feeling and properties of a woollen fabric. These different methods lead to different results, and it is therefore possible to gain a preferable surface and quality [7]. But there are many factors to take into consideration during such a process. The thickness of the fabric is determinate for the result and a silicon treatment that is normally associates with enhancements in softness, gives a harsh effect in fabric handle [7].

Wool fibres feel smoother than most other textile fibres, and also have a much lower coefficient of friction compared with nylon, silk, viscose rayon to mention some [2]. Test with human subjects have revealed that energy consumption decreased by about 7-13% and movability of extremities increased by 10% when low-friction rather than high-friction clothing was worn [10].

3.12 Environmental Impact

The environmental benefits of using wool instead of cotton and synthetic materials are relatively well documented, both in terms of production and use. To the consumers, on the other hand, these advantages are relatively unknown. A change from cotton to wool would by itself add a more sustainable consumption pattern due to a lower washing frequency needed and the durability of the wool material [3]. Durability and reuse are important environmental strategies. The ability of wool to be washed less frequently than other materials due to the lower smell intensity [3], is also of course an advantage for the customer because the garment needing less maintenance. If not exploited wool may cause a waste problem because wool degrades very slowly and is therefore not suitable for composting [3].

Wool, a natural fibre, is non-toxic, has a lower density and is a source of income for agricultural communities [9]. It is also non-abrasive during processing and are fully biodegradable and environmentally friendly [9].

4. HUMAN BODY UNDER EXERCISE

Humans have to maintain a thermal balance to be able to function properly. During exercise the human body undergoes profound changes. While resting the human body produce about 100W, but during exercise this may increase to more than 2000W [1]. This heat has to be evaporated to maintain thermal balance. If more heat is produced than evaporated the core temperature will increase, an uncomfortable feeling will occur, and the human have a tendency to remove garments to maintain thermal balance. If more heat is lost than produced, the core temperature will drop and the feeling of discomfort will occur. Humans then have the tendency to look for warmer garments. Clothing thus plays an

essential role in the maintenance of the thermal and fluid balance with thermal comfort and thermal discomfort [1]. Due to differences between different body parts in sweat production, thermal sensitivity, shape, temperature and so forth, an optimal garment for sports should not be made of a single textile material, but should be constituted of different materials with functions optimized for that part. Human heat balance depends on climate, exercise intensity, garment properties and individual aspects like training status [1].

4.1 How heat leaves the human body

Heat generated through exercise leaves the body through four major channels: radiation, convection, conduction and evaporation [1]. The areas of the body exposed to the environment lose heat through radiation dependent on the emissivity of the surrounding areas. Convection current is created through displacement of heat through body movement with heat transfer increased through air speed. Heat is conducted from the body to the skin surface and from the skin to materials in close contact with the body. When the environmental temperature is greater than skin temperature, evaporation is the means of dissipating heat from the body, with perspiration/sweating as a cooling mechanism against overheating.

4.2 Sweat Efficiency

If the core temperature is too high sweating will occur. The produced sweat must be allowed to evaporate in order to restore thermal balance [1]. Human sweating is minimal (about 350 ml/24 h) under a subject-specific sweat threshold, but increases to values up to seven litres per hour during exercise [1]. Sweating leads to dehydration and the lost water have to be restored to maintain the fluid balance. From a thermal standpoint it is generally preferred to evaporate the sweat immediately [1].

4.3 Exercise in the cold

The energy expenditure(EE) for skiing for example is at EE low 698 W and EE high 1396 W[1]. At times of maximum oxygen uptake the production of heat may reach over 2000 W and this heat has to be lost quickly, or else the core temperature will increase with 5 degrees Celsius in 10 min[1].

4.4 Human responses to cold

The human body produces metabolic heat by using its muscles and organs [10]. Human performance is negatively affected when core body temperatures are not between 36.5 and 37,5 degrees Celsius. Intense cooling of the skin, especially on the face or extremities, causes frostbite. The tolerance for cooling is very dependent on what part of the body that is being exposed. While the fingers can tolerate a temperature of 5 degrees Celsius, the mean skin temperature will not tolerate any lower than 25 degrees Celsius [10]. If the temperature goes below this, damage will occur. Cooling causes discomfort and impair physical and mental performance in various ways [10].

5. CLOTHING FOR EXERCISE IN THE COLD

Clothing is important as a thermal and water vapour barrier between the skin and the environment. When exercising in the cold the clothing insulation has to be adapted to exercise intensity in order to stay in thermal equilibrium [1]. If we have intermittent exercise periods in the cold and do not adapt clothing insulation, heat production will exceed heat loss. Consequently, the body core temperature will increase and sweat will accumulate in the clothing. During the rest periods of intermittent exercise the sweat will evaporate and generate extra cooling (also called after-chill). This may lead to discomfort as well as performance decrement [1]. If the thermal regulation is inadequate the body temperature may raise causing hyperthermia, or drop to cause hypothermia. The core temperature has to lie

within the span of 35-42 degrees Celsius to avoid these extremes [1]. This span is quite narrow, and therefore it is very important to wear clothing that works together with the body on maintaining thermal equilibrium.

5.1 Defining Thermal Comfort

Thermal comfort is the condition of the mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation [1]. The main drivers to determine thermal comfort are ambient temperature, radiant temperature, humidity, wind speed, clothing insulation and metabolic activity. To determine thermal comfort is a subjective judgement that is often classified in a scale from -4(very cold) to 4(very hot).

5.2 Climate

The climate is determined by ambient temperature, wind speed, relative humidity and solar radiation [1]. Another factor to take into consideration is altitude, since ambient temperature drops with increasing altitude. Heat flow is most stressful in cold weather when there are low ambient temperatures, high wind speeds and absence of solar radiation [1]. Also, wet cold ambient temperatures just above the freezing point can form a considerable cold stressor since water takes away the body heat more quickly through convection. Therefore, since the body cools more rapidly when people are wet, hypothermia is more apparent in wet than in dry cold. Since thermal strains is not determined by single climatic parameters it is better to use climatic indices(temperature, wind, relative humidity and radiation) when taking decisions or giving recommendations about sportswear.

5.3 Cold Protective Clothing

People who wear cold protective clothing are normally engaged in dynamic activities, in which they may change their physical activities and go through different external environments and experience a great drop/increase in temperatures. Under such dynamic/transient conditions, liquid water is likely to appear in the clothing systems due to sweating and condensations. This can cause significant changes in the thermal properties of clothing materials and temperature/moisture distributions in the clothing system. Therefore the management of water vapour transfer and liquid water transfer can become critically important when designing clothing systems [5].

5.4 Clothing Effects on Performance in the Cold

Dry unmovable air in clothing provides the greatest thermal insulation. Therefore it is very important to stay dry, and here the selection of different layers is key. In the cold the aim of clothing is to prevent excessive body heat transfer to the environment. However, during high-intensity training with a high level of thermal protection in cold environments, heat strain is possible [10]. When thermal and moisture transfer occurs the qualities of wool can help the wearer stay dry and remain thermal comfort.

5.5 Physiological requirements

Physiological condition, food intake, physical activity, thermal comfort in relation to temperature extremes, and the length of exposure are all factors that determine the physical need for clothing. Clothing comfort is also affected as it restricts or facilitates body movement and protection from the environment. This is why, for the outdoor sector, clothing design, largely dependent on fabric selection, provides an effective means of heat insulation where heat flow may be positive or negative from the body to the surrounding air or from the environment to the body.

5.6 Layering

Materials selected for the inner layer should not retain moisture, as an absorbent layer that retains perspiration from the skin and evaporates heat could be harmful. No artificial fibre can offer

the same combination of qualities as those of wool [10]. As long as the underwear is made of fibre with diameter lower than what causes itching, wool is a superior fabric for the inner layer.

Middle layers adjust the thermal insulation of the clothing and are selected according to the weather and physical activities [10]. Since the still air between the clothing layers and in the textile construction forms about 80% of the thermal insulation of the clothing system, a variety of bulky fabric construction, containing a lot of air, is suitable for middle layer garments. Knits and wool is good because it has a high thermal resistance owing to the relative high air content inside its fibre construction [10]. As an outer layer wool works great as a warm lining material, but will not work sufficiently alone. A shell layer with or without an insulating layer is to prefer [10].

5.7 Performance requirements of fabrics for sportswear

The profile of the end user must be understood in terms of aesthetic and cultural demands as well as physiological requirements in relation to the end use, participation levels and anticipated environments where the clothing will be worn [1]. All these factors taken into consideration and appropriately valued will contribute to an overall "feel good" factor for the wearer. Fabric selection for the outdoor environment must address performance requirements that contribute to overall maintenance of body comfort where appropriate garment design, fabric selection and manufacturing methods are interdependent [1].

6. DISCUSSION

This section seeks to link the qualities of the wool fibre and the human factors during exercise in cold climate. It has been shown that the properties of the wool fibre are obtained because of the composition of the fibre structure. For fine wool the fibre length is under 25 µm and this makes garments of fine wool excellent for garment to be worn close to the skin. Tests have proven that the comfort of wool is equivalent to that of cotton when the fibre diameter of wool is > 18,1 µm [18]. When the wool garment is worn close to the skin the wearer can benefit from the water sorption qualities of the wool fibre. The matrix proteins that are rich in sulfur causes the ability of wool to absorb a large amount of water compared to other fibres without feeling wet. Under high intensity training this is a fine quality that will keep the wearer feeling comfortable despite heavy sweating. From a thermal standpoint it is preferable to evaporate the sweat immediately. During exercise heat has to be evaporated to maintain thermal balance. The wool fibre is superior in helping the body with this task and maintaining its functions, given that the wool fibre is the fibre offering the best breathability in the world. When absorbing water the wool fibre has the ability to absorb a large amount of water without feeling wet, and not feeling wet is important to maintain the thermal comfort of the wearer.

During exercise the body releases fluid, known as sweat. If the sweat is not transported from the skin bacterial growth causes body odours to occur. However, the wool fibre has the ability to absorb and trap the odours inside the fibre until the garment is washed. For the wearer of the garment this means an odour free environment, which may be particularly preferable during activities that vary in intensity. It also results in less maintenance for the user because the garment has to be washed less frequently.

Another fine quality of the wool fibre that the user can gain from is the flame retardancy of wool materials. The low concentration of oxygen, and nitrogen as part of its chemical composition causes this property. If a garment made of wool should catch fire, which in the first place is difficult, the wool will burn to ash, cool immediately and can be removed from the skin. With this property a wool garment can possibly be directly protective of the user. The wool fibre can also protect the user from UV radiation.

Wool garments are sun safe and this is a highly appreciated quality that the user can benefit from when exposed to sunlight. This makes wool garments great to wear during activities when the wearer is exposed to solar radiation.

In cold climate the user is dependent on insulation to stay warm and maintain thermal comfort. The wool fibre can also meet this challenge. The othocortex gives the desirable crimp in fine wools that gives the fibre bulkiness. The bulkiness increases the amount of entrapped air in the wool fibre. The best thermal insulation is dry unmovable air, and hence the wool fibre is excellent when it comes to keeping the user warm.

After being used garments tend to wrinkle on areas where body parts bends and moves. This can for example be on the arms of a sweater where the elbow bends. For the garment to appear as durable it is important that these wrinkles straighten out after use. A wool garment has excellent wrinkle recovery, as the wool fibre has the second best wrinkle recovery properties after polyester. This is because the cortical cells are composed of crystalline proteins called intermediate filament, giving the wool its elasticity, resilience and good wrinkle recovery. Therefore, the wool fibre provides wool garments qualities that the user can benefit from after as well as during use.

7. CASE STUDY: WOOL GLOVES FOR ALPINE TOURING

To link the qualities of wool and the challenges of high intensity training together a case study was conducted. The goal was to verify the findings in the article and prove wool as a fine material for exercise in cold climate. The study and findings are presented below.

7.1 The case

The study took place in Sunnmørsalpane, on the west coast of Norway. The study involved nine different users testing wool gloves for alpine touring. The prototype was specially designed to fit the demanding conditions the user experiences when climbing a mountain in wintertime. The glove had a knitted structure and was made out of 100% merino wool. The gloves were to be used under alpine touring; skiing trips when you walk up a mountain and ski down. The gloves were especially designed for the walk up the mountain when the user is under physical stress. During the walk up the mountain the user would get to test the gloves, a garment of wool, while training in a cold environment. The feedback from the users would then strengthen or weaken the link between woollen garments and high intensity training in cold climate.

7.2 How the testing was conducted

The test followed the method of Cultural Probes. This was a good way to get insights from many users during a short period of time. The Cultural Probe Kit consisted of an individual pair of gloves and an information brochure. 9 participants were asked to join the test. The participants were 4 ladies and 5 men. They were all people with experience within alpine touring. The participants had an age span from 24 to 54 years and rated their physical condition from 5 to 8, on a scale of 1 to 10. The test went on for two weeks, and during this time the participants were to use the gloves on as many alpine tours as possible. During the trips the participants should take pictures, think about the feeling of the material and the feeling of their hand during the activity. After the trip this insight should be written down on paper, together with information about the trip such as weather conditions and destination.

The test period was held in the end of April. The weather during the two test weeks was very variable, as predicted on the west coast of Norway. Some days were sunny and warm, while some days were windy, cold and had a lot of snow. Different weather conditions were great in concern of the testing of the gloves. The users got to test the gloves in a temperature range from -10 to 5 degrees Celsius.

After the test period the participants handed in written feedback consisting their thoughts, experiences and an overview of their trips. The gloves were also handed in for inspection. This was important to compare the wear and tare of each pair, and see how the use had affected the material. Nevertheless, the written feedback from the participants was most valuable to strengthen the believe of merino wool being a good material for gloves to be used under high intensity training in the cold.

7.3 Findings

The feedback from the study was compared and analyzed. From the nine participants a general impression of the gloves could be made. Every participant was very satisfied with the material of the gloves. The comments on the materials were solely positive except from one experience one of the users had on one of his trips. He had tested the gloves under demanding weather conditions with heavy snow and a lot of wind. Under these conditions the gloves were too cold, and in need of a water repellent layer. Otherwise the participants commented that the material was great for alpine touring. The gloves kept them warm, but not to warm by managing to regulate the temperature.

There where no complaints that the user felt wet because of sweat during use of the gloves. The participants were very happy with the breathability and water sorption of the material. One participant said that she used the gloves on a trip where the weather was very warm, and she was surprised that she could wear the gloves without feeling too warm. She walked up the mountain wearing only a thin sweater made of wool and the gloves. Even though she was sweating heavily the material of the gloves did not feel wet or uncomfortable on the skin.

The knitted gloves had a firm fit which some of the participants first thought might be uncomfortable. However, this was sown wrong to the participants when they got to use the gloves and the shape adapted to fit their hand and movements. Many of the participants mentioned this as a fine function of the material that was highly appreciated.

8. FINAL REMARKS

This article has investigated the wool fibre and its usability as a material for garments to be used under high intensity training in the cold. The qualities of the wool fibre and how these characteristics are obtained have been presented. Challenges that the human body encounters under training in cold weather are also accounted for. To link these qualities and challenges together a case study was conducted where woollen gloves for alpine touring were tested. The test resulted in feedback verifying that the wool fibre is an excellent choice as a material for garments to be used under exercise in cold environments. Specially valued features of the wool fibre were the breathability, the water sorption and the low friction qualities.

The wool material showed a good response to high activity in cold climate. The qualities of the wool fibre are able to meet the challenges the human body encounters during exercise in low temperatures. Both the investigation of the wool fibre through the literature review and the case study verified this link. It is clear that the properties of the wool fibre can and should be exploited when designing garments for exercise in cold climate.

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