

Rock-climbing apparel: An analysis of current clothing options and future strategies for the design of rock-climbing clothing.

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Rock-climbing apparel: An analysis of current clothing options and future strategies for the design of rock-climbing clothing.

This paper identifies and analyses current clothing options available to rock climbers in New Zealand, drawing from data collected via a survey of experienced climbers, relevant literature and a detailed design analysis of garments that are currently on the market. The study considers some of the limitations of current rock-climbing clothing and identifies issues that need to be taken into account to design more practical, responsive, sustainable clothing options for climbers. Drawing on professional design expertise in patternmaking, material selection and garment construction, this analysis is used to inform the development of more appropriate and innovative garment design strategies for rock-climbing. It also recognises the potential for novel development by employing innovations from the field of advanced textiles and apparel, in particular the integration of smart sensing technologies into garments.

Keywords: rock-climbing clothing; garment design; garment analysis; patternmaking, smart clothing

Introduction

In recent years, rock-climbing has established a growing and significant niche within the realm of adventure activities. The popularity of rock-climbing has spread globally, diversifying to include new categories such as ice climbing and bouldering. In 2016, the International Olympic Committee added Sport Climbing to the programme of games offered at the Olympic Games Tokyo 2020 (International Federation of Sport Climbing, n.d.). In New Zealand rock-climbing is a popular activity with over 19,997 climbing routes distributed across the country (The crag. Aoteroa/New Zealand, n.d.). There are many rock-climbing clubs including the oldest one in the world, the New Zealand Alpine Club (NZAC), a community of 4300 plus members (New Zealand Alpine Club, n.d.). The availability of potential participants (experienced climbers) to gather information was a key reason this research was conducted in New Zealand. The

research takes a human-centered approach (Cherrington et al., 2020; Putnam et al., 2016) based on an in-depth understanding of the users (climbers) needs through questionnaires, observation of climbing movements and positions, an analysis of current clothing options and user testing of prototypes. It is also informed by issues of sustainability (Motlogelwa, 2018; Niinimäki & Armstrong, 2013).

Rock-climbing is a physiologically and psychologically demanding sport that is influenced by external environmental factors. In parallel with its increasing popularity, the number of climbing accidents and emergency department consultations due to climbing related injuries has increased (Rauch et al., 2019). Climbing can be a dangerous activity and knowledge of proper climbing techniques, tactics and use of specialized climbing equipment and ergonomic clothes are crucial for the safe completion of routes. Ergonomics in clothing can be interpreted as the consideration of comfort and performance factors in the design of clothing which is made for a specific end user requirements, determined by the environment in which the user operates and the activities are performed (Gupta, 2011; Jayasinghe & Seram, 2017). In a paper on the ergonomics of industrial, sport protective clothing and sport clothing, Bishop et al. (2013) reviewed the interactions between humans and clothing, with a view to optimize human comfort, safety well-being and performance. The authors (Bishop et al., 2013) identified thermoregulation as an important aspect of clothing ergonomics. The vapor and moisture permeability characteristics of the clothing play a critical role in influencing the micro-environment and consequently are important for wearer comfort (ibid). Moreover, for types of rock-climbing such as ice-climbing and alpine climbing, appropriate rock-climbing clothing can prevent hypothermia (Coalter et al., 2010), which is an independent risk factor for mortality in trauma patients. Severely injured climbers are often hypothermic (Rauch et. al, 2020).

However, there is a lack of published standards and requirements for the apparel needs of rock climbers and a limited number of researchers working in this area. This paper presents an analysis of commercially available clothing made for rock-climbing. The research considers some of the limitations of current rock-climbing clothing and identifies issues that need to be taken into account in designing more practical, responsive, sustainable clothing options for climbers.

Literature review

The literature search identified a limited number of studies in this area that were generally restricted to particular types of rock-climbing clothing. For example, in Choi & Kyung's paper, the authors investigate the diverse construction characteristics of outdoor rock-climbing jackets which significantly affect performance (2018). In addition, they consider the materials information provided to consumers on functional clothing. They found that the degree of fit, backpack weight, arm-raise, and number of pockets vary considerably, effecting the performance level of outdoor jackets (ibid). Considerable construction differences were found between high performance jackets, mainly worn by professional climbers in extreme environments and jackets that are worn in daily life. The study also found that different characteristics were not only related to each different and complex constructive aspect, but also to a garments ability to stretch, its resistance to water, venting system and materials that effect the performance level of an outdoor jacket. In an article by Michaelson et al., the authors assessed rock climbers' pants selection by investigating whether a pants' style or brand preference exists among rock climbers, along with a consideration of fit, mobility, comfort, protection, and donning/doffing (putting on and taking off) expectations for climbing pants, using a mixed-methods design study (2018). The researchers found that rock climbers needed improvements in areas such as pants' fit, sizing options, and

design in relation to the functions of mobility, comfort, protection, and durability (ibid). Additionally, climbers wanted affordable pants that would not interfere with their rock-climbing techniques or equipment. Another paper (Im & Park, 2017) examined elements that affect the actions of sports climbers and suggested an ideal pattern archetype of sleeve to maximize function based on motion. The theoretical background to this study included abstracted elements influencing clothing design by researching the body types of sports climbers and the motion of sports climbing.

An investigation of the needs and preferences of women regarding rock-climbing apparel to inform the design of female climbing clothing is described in a paper authored by Johnston & Koo (2017). A total of 20 female rock climbers were interviewed using a purpose sampling method, and the results indicated that many of the subjects were not satisfied with their climbing clothing's fit, colour, and durability. The majority of interviewees (90%) were dissatisfied with the fit of their climbing pants with 85% of participants experiencing rips, holes, and split seams (Johnston & Koo, 2017). Many participants (80%) preferred hip length shirts to prevent the shirt from rising above their harness and 85% of subjects preferred tighter fitting pants (ibid).

An analysis of current databases and requirements for rock-climbing identified that current standards cover the safety and reliability of climbing-specific gear, definitions of terminology, design, performance and inspection standards, and training standards. However, there are no standards and requirements for the apparel needs of rock climbers. While outdoor apparel manufacturers have been designing rock-climbing clothing with some functionality, their efforts do not always meet climbers' expectations due to the lack of data on requirements and general principles for sport specificity and climbers' needs. Climbers make clothing decisions based on their needs, expectations, and experience with existing clothing. In addition, while there are growing

numbers of smart wearable applications in the healthcare and high-performance sport sectors, developments for rock-climbing have been limited. To date, the majority of wearables for climbing have been designed as activity trackers, for example to track movements and assess climbers' performance during their workout in indoor gyms by offering a visualisation after the ascent (Mencarini et al., 2019). In another example, Ladha et al. (2013) designed and evaluated ClimbAX, a wristband able to detect the power, control, stability, and speed of a climber. Mencarini et al. (2019) in their project designed and deployed a vibrotactile wearable device aimed at augmenting the communication between instructor and trainees and assessed its usefulness, usability, and pleasantness during an indoor climbing lesson. The goal of the prototype was to support the learning of the proper climbing technique and at same time make the climbers feel reassured by the attentive presence of the instructor. The prototype was composed of eight vibrating devices to be worn by climbers and controlled by the instructor through a tablet. This is a field with significant potential for the novel development of smart textiles and functional apparel, involving the integration of innovative technologies such as smart sensing technologies into clothing, to enhance safety, comfort and performance.

The specific focus of this paper on the analysis of clothing for rock-climbing is part of a larger study into the potential of smart clothing for rock-climbing. This paper presents findings of part of this ongoing inquiry. It draws from data and an analysis of a survey and a detailed design analysis of rock-climbing garments that are currently on the market. A qualitative heuristic approach to data analysis has been adopted. Through this study key factors that need to be taken into account when designing garments for rock-climbing are identified. Ways of addressing these issues through the considered

integration of garment construction, fabric selection and the use of smart technologies are proposed.

Methods

The survey.

Qualitative research, in the form of a questionnaire, was used to better understand the experience and problems faced by climbers related to clothing. As there is limited literature published about rock-climbing clothing, this primary research has been critical to understanding problems and potential areas of design intervention. The questionnaire ‘Rock climber's clothes - satisfaction, preferences, requests and needs of rock-climbers’ was delivered online using Qualtrics (<https://www.qualtrics.com/>). The participants, all experienced climbers, were selected using a purposive sampling method (Campbell et al., 2020; Etikan, 2017). Purposive sampling was selected for this project because the quality, qualification and experience of participants’ responses are more valuable for gaining design insights than the number of respondents. Qualitative questions included the description and evaluation of individual climbing experience, experience with existing rock-climbing clothes and the identification of opportunities for using smart technology.

According to the International Rock-climbing Classification Systems (*International Grade Comparison Chart*, 1999) climbers’ abilities are classified as:

Beginner (Yosemite Decimal System (YDS) 5.2-5.9, AUS 10-17);

Intermediate (YDS 5.10a-5.11d, AUS 18-23);

Advanced (YDS 5.12a-5.13d, AUS 24-31);

Professional (YDS 5.14a-5.15c, AUS 32-38).

Only climbers at intermediate or higher levels of experience were selected for the survey, with preference for climbers who are experienced in at least one particular outdoor rock-climbing style such as mountaineering, traditional climbing (including multi-pitch trad. climbing), and winter (ice) climbing. Beginners and inexperienced climbers were excluded from the study. The inclusion and exclusion criteria were made explicit in the participants information sheet. The questionnaire also asked about the participants' previous climbing experience (questions 3-5) and any novice climbers not previously identified were excluded at this stage.

The questionnaire consisted of thirty to thirty eight questions, depending on the participants selection. There were four questions on climbers' preferred types of clothing and brands for outdoor climbing, and their preferences in terms of aesthetic, colour, fibre and fabric. Two questions related to factors that were deemed most important by climbers when they purchase rock-climbing clothes. There were four questions asked about the quantity of layers of clothing climbers usually wear and their experiences while removing or putting on clothing while rock-climbing. Three questions asked about microclimate regulation inside clothing layers. In addition, there were six questions regarding clothing and smart technology.

A qualitative heuristic approach was used in the data analysis (Moustakas, 1990; Nielsen, 1994). Heuristic analysis is an inspection method that takes an experience-based approach to problem-solving. The heuristics developed in this project take into account factors such as comfort, fit, flexibility, portability, etc. depending on the final area of application. Seven participants at advanced and intermediate levels took part in the survey. They were asked about preferred types and styles or designs of clothes for outdoor rock-climbing, and the brands of clothes they prefer to wear while performing

rock-climbing. Open-ended questions were analysed using a content analysis approach to understand participants' perceptions and experiences with their existing clothing.

Clothing analysis.

The purpose of this analytical study of existing outdoor rock-climbing sportswear that is currently available on the market is to provide a detailed analysis of the technical design solutions of such clothing, providing better understanding of existing clothing ranges for outdoor climbing, their performance, functionality, and materials selection. Outdoor rock-climbing clothing of six well-known brands, identified by climbers in the survey, were selected for this analysis. Participants mentioned seven preferred brands including *Sivera*, *Black Diamond*, *Arcteryx*, *NorthFace*, *PrAna*, *Marmot*, and *Kalborn*. Six types of rock-climbing clothing (pants, bibs, men's and women's jackets, parkas, overalls) from these brands were then selected for further detailed design analysis of garments. Only the brand *Kalborn* was excluded from the analysis as the clothing is designed without a specific rock-climbing focus.

Results

Survey Analysis.

Key findings identified constructive features, fabric and fibre preferences, colour preferences, durability and thermoregulation issues, and smart technologies.

Almost all participants wore helmets while rock-climbing with only one respondent answering that they wore a helmet 'sometimes'. More than half of respondents wore a hood, and 75% of them needed the hood to provide additional protection to the lower part of their face, for example against the wind. Most respondents reported negative experiences while wearing a hood, especially due to restricted hearing or seeing.

Over 70% of respondents used pockets. Participants identified the preferable number of pockets as between 2 to 4 in a jacket. The best placement for pockets on clothing for climbing took into account equipment, movement, accessibility and other factors. All respondents identified chest pockets (internal and outer) as the best option in a jacket. Pockets on the sleeves were described as good but not always convenient to use. Pockets in pants are a controversial issue in terms of placement because they are restricted by a harness (as shown in Figure 1). Respondents noted ‘While they (pockets in pants) are good for general purpose climbing they are not useful when wearing a harness’, and ‘Pockets in the legs of pants often are blocked by a harness’, or ‘Pockets that are in the legs should be lower than a harness’.

Figure 1.

Respondents were asked to identify parts of clothing that have problems in terms of abrasion affected by equipment, ropes, harnesses, rocks, and the most frequent areas that have durability problems in the rock-climbing clothing they typically wear. Jacket abrasion is mainly around the cuffs and pants abrasion is around the knees. In terms of durability problems, climbers also mentioned the knee area in pants (28.57%) and legs in general (19.05%), and the areas of a sleeve and cuff in jackets of 40% and 33.33% respectively.

Three questions were related to the microclimate inside clothing layers.

Respondents were asked to identify specific experiences with climbing clothes in relation to temperature (heating or cold) and humidity (wetness) while rock-climbing. In addition, they were asked how many layers of clothing they usually wear and how they normally regulate the microclimate inside clothing layers (level of humidity or temperature) while rock-climbing. The experienced climbers specified that they wear at least two layers of clothing and the microclimate inside clothing layers is regulated

mostly via opening up zips, opening the collar or using different clothing options. If the climber is getting too hot or cold, he/she must stop and take off or put on another layer; so, they have a multi-layer approach to their clothing.

In terms of the preferences that climbers developed over time through experience, all respondents mentioned fabric and fibre preferences: favouring stretch fabric and mixed synthetic and natural fibres. In relation to colour preferences, some respondents specified bright colours for safety, while others preferred quiet colours that blend into the environment. However, it was also mentioned that ‘nice to have options’ such as colour choices were limited, especially for women in New Zealand.

The most important factor identified when climbers purchase their outdoor rock-climbing clothes was the fit of the garment; while fabric type and cost came in at second place. Garment fit is not purely about body shape and size but is influenced by factors such as gender, age, ethnicity, lifestyle, cultural influences, and so on (Michaelson et al., 2018). A wearer’s perception of fit is derived from how a garment conforms to the body (Michaelson, 2015). Perceived fit can also depend on characteristics such as comfort (psychological and physiological) and range of motion (Michaelson, 2015). Therefore, fit is also affected by ergonomic design, that is clothing design that includes the topography of the body (Neves et al., 2015) and anthropometric characteristics in static and dynamic states. Clothes fit, practical design and durability of material are important factors for rock-climbing clothing as this type of garment has longer lifespan (Klepp et al., 2020). Climbers will wear and use such garments for a longer period which extending the garment’s lifecycle, thus making it more sustainable.

There were six questions in the survey regarding clothing and smart technology. Firstly, respondents were asked ‘Have you used any smart devices while performing rock climbing? Please specify’. The majority of respondents (71.43%) have used

different smart devices. These included smartphones with a global positioning system (GPS) and, for looking at the route topography, a smartwatch, or a Garmin watch, and a barometer to measure height and rate of climb. Also, barometers were used to monitor any radical pressure drops, indicating beyond visual line of sight that bad weather was coming. None of the respondents had used any integrated smart clothing while performing rock-climbing. However, 71,43% of respondents said they would like to have rock-climbing clothes that integrated with smart technology.

In addition, participants were asked for their opinion on which sensors would be more important for rock-climbing clothing. The results of this multiple-choice question are summarized below in Table 1. Experienced climbers would like to have outdoor rock-climbing clothes that integrated with smart technology to measure and regulate temperature and humidity level inside clothing and measuring body vital signs. However, one climber specified 'Weather, location and perhaps passive communication' are more important than sensor capability.

Table 1.

Clothing analysis.

The outdoor rock-climbing clothing ranges of six well-known brands were selected for this analysis. The criteria for selecting the types of the rock-climbing clothing to be analyzed included the preferences of more experienced climbers for outdoor climbing clothes and design strategies related to pattern construction, functionality, and ergonomic solutions that were distinctive to rock-climbing clothing. In general, the types of outdoor rock-climbing clothing which are commercially available are mostly jackets and pants, including bibs. For extreme cold climate conditions, warm overalls are produced, but this type of clothing on the market is limited. Sets of semi-overalls and jackets are more prevalent.

Fibres and fabric characteristic. From an analysis of fabric selections, it was determined that fabrics made from synthetic fibres are more prevalent than natural fibre options. For example, the brand *prAna* uses 95% recycled nylon and 5% elastane for their rock-climbing pants. A composition of nylon and elastane fibres is common to all brands. This fibre combination is used in different proportions for climbing pants and some jackets, where flexibility is important. Incorporating elastane fibres into fabrics provides high tensile properties (Akter, 2020; Qadir et al., 2014). Elastane fibres, also known under trade names such as Spandex, Lycra, Dorlastan, and others, have exceptional elasticity, with an extension-at-break greater than 200% and also show rapid recovery when tension is released (Senthilkumar M et al., 2011). These fibres exhibit rubber like behaviour with high reversible extension of up to 400 - 800% (Senthilkumar M et al., 2011). These fabric characteristics enable freedom of body movement by reducing the fabric resistance to body stretch (ibid). Rock-climbing pants, but rarely jackets, can be made of fabric that consists of natural fibres in combination with synthetic fibres.

In addition, some manufacturers use fabrics with flexible weave or knit structures along with stretchable fibres to provide these properties. Thus, *Black Dimond* uses a single-weave, four-way stretch woven fabric that consists of 85% nylon and 15% elastane for their Alpine Light Pant. Other represented manufactures also use nylon or stretchy nylon/elastane blend textiles for outdoor rock-climbing clothing.

Durability. Areas of clothing that have durability problems are often strengthened with fabrics that prevent punctures and rips, or that have abrasion-resistant properties. Manufacturers also use textile materials with different types of finishing, such as durable water repellence (DWR), to improve the durable characteristics of clothing. DWR reduces the surface tension of the fabric, so that water simply rolls off. For instance, Recon Stretch bibs-men's (*Black Dimond*) has reinforced parts of their pants with nylon

double-weave fabric with DWR finish. The lower-leg exterior of the Men's Summit L5 Futurelight™ Full Zip Bib (*North Face*) made from 75D x 100D 141 g/m² Futurelight™ 3L-91% recycled polyester, is reinforced by 9% polyethylene Spectra® ripstop with 100% recycled nylon tricot backer and DWR finish.

Protection. Brands such as *Marmot* and *Sivera* that make rock-climbing clothing for extremely cold weather conditions, provide superior wind and water protection and warmth for ‘summit bid-worthy adventures’ (*Marmot*, n.d.) use 100% Nylon for the outer layer of clothing and different types of insulation. For the WarmCube™ 8000M Suit and the Unisex West Rib Parka, *Marmot* combines 800-fill-power goose down and Pertex Quantum® fabric (100% Nylon, Dobby, 70g/sqm). *Sivera* also uses high-quality goose-down SmartDown FP 700+ 501g with hydrophobic treatment for insulation. In addition, many manufacturers develop their own technologies to improve the characteristics and functionality of rock-climbing clothing. For example, *Marmot* uses their own, patent-pending, WarmCube™ construction technology for ultra-comfortable warmth in extreme conditions.

From an analysis of fasteners that manufacturers use in their clothing, several different types of fasteners were identified, including zippers, buttons, snaps, velcro tape, elastic, etc. Fastening systems in rock-climbing clothing provide mobility and protection. Thus, some manufacturers use technical zipper vents in pants and jackets for ventilation to prevent overheating. For protective and functional clothing, fasteners must be positioned for comfort and easy access (Shanley et al., 1993), and can aid in the donning and doffing process (Michaelson et al., 2018).

Pattern Engineering.

Climbing pants, jackets and overalls were assessed using the commercially available samples of clothing and information from the manufacturers' webpages. A detailed analysis of the design solutions for represented types of high-performance clothing designed for outdoor climbing identified the main principles of pattern engineering for such clothing, providing fit, mobility, ergonomics, and comfort. A summary of this analysis is presented below.

Climbing pants. The main features identified in the patterning of climbing pants through this analysis included:

- the waistline is fitted higher, so it does not fall under a harness;
- adjustable, tightened waistband;
- attached, adjustable suspenders for bibs;
- seat gussets allowing for more movement in the hip and leg area, allowing the climber to have a wider range of movement;
- articulated patterning of knees area - this feature is incorporated by the addition of extra darts around the knee area to bring more roominess in this area;
- correct length with options for rolling up and incorporating functional adjustments, for example adjustment on the bottom of the pants, allowing them to be used as 3/4 shorts;
- an anatomical design that provides an optimal fit and realized by addition of extra darts, correct eases and the patterning of the constrictive lines which duplicated the shape of a body;
- some pants have technical zipper vents on either side for ventilation;
- pockets with easy access - pockets must be placed correctly so they are not blocked by a harness;
- pockets are usually zippered to protect belongings from falling out;

- the line of pocket's access must be straight as a zipper cannot be inserted into a curved pocket seam allowance;

Jackets. The main features in pattern construction for jackets and overalls designed for climbing are:

- fit that provides freedom of movement with room for layers;
- a front and/or a back yoke are typical for rock-climbing jackets - the shoulder dart is converted into a back yoke line;
- for women's rock-climbing clothing a bust dart may be converted or partly converted into a front yoke line;
- a hem line may be straight or with a slight drop-tail, with adjustable hem drawcord mostly - for example, in the Alpha AR jacket men's (*Arcteryx*) Cohaesive™ hem adjusters function as Hemlock™ to prevent a jacket from slipping out from under a climbing harness;
- the jackets designed for cold weather conditions have a protective inner skirt with stretch panel and gripper elastic;
- some manufacturers (*Arcteryx, North Face*) designed a seamless shoulder line which makes carrying a pack more comfortable;
- two main types of sleeve construction were identified during the analysis of existing clothing- these are a plain sleeve and full sleeve; their manipulations provides a greater range and freedom of motion in the sleeve area;
- it is interesting that a raglan sleeve, which is a preferred style for sportswear, was not detected among outdoor rock-climbing clothing of selected brands - the most likely reason for this is the restriction of arm movement; as many manufacturers use non-

stretchable fabric in their jackets, a raglan sleeve may restrict upright arm movement that is a very common body position in rock-climbing.

- a sleeve may have an elbow dart to provide ease of motion and better fit;
- some clothing has lift gusseted underarms;
- a sleeve hem is primarily finished with a cuff - cuffs may be relaxed to fit over gloves or, oppositely, are close-fitted around a wrist;
- cuffs are mostly adjustable with Velcro;
- adjustable and helmet-compatible hood configuration - the hood may have adjustments along the hood face opening length to make it more contoured and/or horizontal adjustments for volume regulation; generally, hood adjusters are glove-friendly;
- all analysed jackets have an attached hood integrated with a tall collar to protect the lower part of the face from the wind - for example, the Sabre LT jacket men's (by *Arcteryx*) has an attached adjustable and helmet-compatible hood with an integrated tall collar that covers the chin, mouth, and nose tip;
- overheating and other thermoregulation issues are solved by including armpit zip vents. For greater convenience, two-way zips are used;
- pocket configuration: hand pockets, chest pockets, and internal pockets were identified as the primary types; some jackets may have one side or both side sleeve pockets;
- the pockets are mostly zippered;
- the pockets should be easy-to-reach so the placement of a harness and rope must be considered;

Discussion and Conclusion

Data from the survey and the analysis of existing clothes identified a number of issues that should be taken into consideration in the design development of rock-climbing

clothing. Rock-climbing clothing must be durable enough to protect the wearer when making extreme movements and in potentially harsh environmental conditions. It also must be lightweight while enabling humidity and thermoregulation. In addition, rock-climbing clothing must properly fit as such garments have a longer duration in use, thus making them more sustainable. To achieve these different purposes, more integrated approaches to the design, pattern making and fabric selection for garments are required.

The main fabric used should be lightweight and strong, waterproof and brightly coloured. Bright coloured clothing is preferable for safety reasons as it can provide great contrast to a rock background in case a climber requires a rescue, and will better reflect sunlight, keeping the climber cooler in warmer afternoon temperatures.

Regarding fibre selection, a combination of natural and synthetic fibres was considered desirable. As all respondents mentioned stretch fabric as preferable. Elastane fibres should be included in fabric composition, as this type of fibre can provide optimal tensile characteristics depending on the percentage of elastane fibres included.

Nowadays mixed natural and synthetic fabrics are often used for rock-climbing pants to provide additional flexibility and ergonomics. Jackets for outdoor rock-climbing are usually made of synthetic (mostly nylon, rarely polyester) fabrics. The most likely reason for this is the light weight of nylon fabric and its higher moisture absorption and better wicking capabilities in comparison with polyester (di Domenico et al., 2022). In terms of durability issues in rock-climbing clothing, the areas around the knees and the cuffs were identified. These areas should be strengthened with fabrics that have high abrasion-resistant characteristics.

Thermoregulation is a big issue for active sports clothing. Climbers have taken a multi-layer approach to clothing in order to regulate the microclimate inside clothing layers, by removing or putting on an additional layer of clothing while rock-climbing.

Some manufacturers address this issue by using armpit zip vents to avoid overheating, because the waterproof synthetic (nylon) fabrics that are usually used as an outer layer in jacket cannot provide enough breathability. However, this issue might also be solved using new generation textile materials and new technologies. Recent progress on advanced textiles for personal thermal management and their significance in energy efficiency are reviewed in the paper (Peng & Cui, 2020), and such textile options will be investigated further through application and testing in our ongoing research.

The next phase of work for this ongoing project will be an investigation into the incorporation of smart technologies and the development of clothing items to enhance performance, safety, and comfort through the integration of smart technologies into garments. The potential and integration of smart technologies into rock-climbing clothes will involve the identification of technological components and the optimal placement for the positioning and integration of sensors in terms of fit, comfort and contact with skin. For this project, based on identified climber needs, it is anticipated that consideration will be given to a digital-output, relative textile-based humidity and temperature sensors for microclimate control in clothing. This ongoing research will further consider the relationship between garment design and construction and the integration of smart technology components to optimise technology performance and minimise any impacts on wearability and durability of the garment. Overall, future research will continue to focus on the development of more appropriate and innovative rock-climbing garment design strategies that consider different aspects and needs identified by experienced climbers, clothing analysis, and design practice. It is anticipated that outdoor apparel manufacturers could improve climbing clothing designs by utilising this study's results.

Statement of Ethics

Research stages that involve human research participants are covered by the Ethics Application 21/171, approved by the Auckland University of Technology Ethics Committee (AUTEK).

Disclosure statement

The authors report there are no competing interests to declare.

Data availability statement

Data sets associated with this paper can be requested to the corresponding author.

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Table 1. Results for Question 34 – ‘In your opinion, which sensors are more important for rock climbing clothing? (You can choose more than one option)

Proposed Answers:	%	Total number of answer
measuring and regulating temperature inside clothing	26.32%	5
measuring and regulating humidity inside clothing	26.32%	5
measuring and tracking movements	15.79%	3
measuring body vital signs (temperature, pulse rate, respiration rate, blood pressure etc.)	26.32%	5
other, please specify bellow	5.26%	1
Total	100%	19

Figure 1. Pocket in climbing pants restricted by a harness (©Novikova).

