An ergonomic solution for ventilating backpack design

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Abstract. Comfort issue is one of the major concerns regarding backpack design. Previous studies have tried to improve backpack comfort in different ways such as reducing load weights and balancing the load distribution. However, few studies have investigated the issues related to thermal comfort, which is a fundamental problem for bicycle rider with backpacks. This study aimed at improving the user's experience for those who cycle with backpacks by providing a better ventilation design and body support. Interviews were firstly completed among fifty participants to investigate their usage pattern and usability issues regarding backpack use. Following, a test was conducted with participants to find out the possible difficulties and problems when cycling with a backpack. The main sweating areas on the back were identified. Design criteria were formulated, and a product prototype was developed accordingly. An experiment was then conducted to evaluate the effectiveness of the ventilation design in two conditions of walking and cycling. Skin temperatures of the back were measured using the infrared thermographic camera. Results showed that the shell support of the backpack design could provide better air circulation in the gap between the body and the backpack. Wearing the ventilating backpack could significantly decrease back temperature and improve the user's thermal comfort while cycling.

Keywords: Backpack, Ergonomics, Ventilation Design, Thermal Comfort.

1 Introduction

Backpacks are commonly used in various outdoor exercises and sustainable commuting, such as cycling and walking [1]. In these activities, backpacks are helpful in carrying daily necessities or heavy loads from place to place, but any improper design or incorrect use of backpacks can easily cause discomfort or even injury for users [2]. Thus, ensuring the backpack comfort is essential for high-quality outdoor activities, which would further contribute to encouraging active lifestyles and lower carbon footprint among urban citizens.

The comfort issue of the backpack has been extensively studied in the field of ergonomics, especially on the topic related to school children and military use. Early studies mainly focused on the load weights and load positioning of backpacks. It has been reported that carrying a backpack can decrease walking speed [3-4], increase loads on lumbar intervertebral discs and induce a trunk forward lean [5-6]. Thus, a maximum weight of 10% to 15% of the body weights was recommended for children backpack design based on previous studies [7]. Besides, it has been suggested that backpack with a higher load position performs better than that with a lower position in terms of oxygen consumption, minute ventilation, trunk posture and subjective preferences [8-9]. Accordingly, some ergonomic solutions for backpacks were proposed, such as purposely separating the backpack into several parts for different contents [8, 10], or adding backpack pockets at the front of the trunk to balance the load distribution by bringing the center of gravity as close to the body [11-12].

During backpacking, the energy cost and heat production are primarily increased because of the external load and body motion [8, 13]. Previous studies have shown that efficient heat transfer between the skin and ambient air is critical for thermal comfort [14-15]. Heat stress can negatively affect a user's exercise performance and body health [14, 16-17]. Nevertheless, products that are in contact with the skin may confound the heat transfer to a certain degree. For instance, it was reported that wearing a facemask could result in high face temperature, which was detrimental to users' overall thermal comfort [18].

Hence, in order to improve the ventilation cooling, contemporary products such as fabrics, clothing, and personal protective equipment are designed in various ways. For example, researchers have tried to accelerate the heat and moisture release by employing special cutting in clothing design, such as creating a 'flared' drape. It has proved that this could significantly reduce thermal insulation under windy conditions [16]. Some ventilation features, such as clothing spacers and mesh opening, are also suggested as solutions for garment ventilation design [19]. In addition, Purvis and Tunstall [14] indicated that a better fit between the human body and the product surface could result in higher ratings of thermal perceptions, although they didn't find its effects on the heart rate, skin temperature, and sweat rate. Therefore, with the aim of decreasing skin temperature and improving the thermal comfort in product design, it is essential to accelerate the rate of heat transfer and evaporation through efficient air exchange.

It is not surprising that wearing a backpack can easily result in thermal discomfort during outdoor exercises. However, studies on the thermal comfort of backpacks have been largely ignored. In Hong Kong, this situation can become even worse due to the hot and humid environment. The outdoor exercises such as cycling and hiking, produce larger amounts of heat and sweat than daily activities [19]. Furthermore, the use of backpack imposes a barrier to air exchange between the back and external environment, which significantly reduces the heat transfer and evaporation from skin surfaces [20-21].

In this study, we proposed an ergonomic redesign of cycling backpack with the objective of improving backpack thermal comfort by providing a better ventilation design and body support. Interview and test were firstly completed aimed to investigate the usage pattern and ergonomic issues related to backpack use when riding a bicycle. Accordingly, the design criteria were formulated, design solution was proposed, and product prototype was developed. An experiment was then conducted to evaluate the effectiveness of the ventilation backpack design. This article describes in detail the application of ergonomic principles in an iterative design process of ventilation backpack for bicycle riders.

2 The user research

The user research comprised two parts: (a) a structured interview on users' habit and personal opinions of cycling backpack, and (b) an experimental test on the realistic difficulties and problems encountered by bicycle riders with backpacks.

2.1 Interview

A structured interview was planned as the first step to generally understand how people use and feel about the backpack in daily use. In this phase, we recruited participants who usually carried backpacks for commuting. Questions were asked about their use habit, including frequency of cycling and belongings inside the backpack, and their personal preferences and opinions, including reasons for using backpack and problems related to backpack use.

In total, 50 participants (27 males and 23 females) took part in the interview. Among them, 40% of participants chose the way of riding a bicycle to work, and 60% of participants chose other commuting strategies. Four kinds of belongings were reported to be frequently carried: water bottles (32%), personal accessories such as keys, wallet, and phones (26%), umbrellas (20%), clothes (15%) and laptops (7%). It was reported that comfort issue was the first consideration when participants chose the way of carrying loads. Heat ventilation of backpack was one of the most problematic issues for the participants. They suffered from heavy sweating on the back, which considerably decreased their thermal comfort when carrying backpacks. Although participants thought the backpack could support their body movement in general and distribute the loads when riding bicycles, they complained that most of the backpacks could not adequately support some body movements such as twisting or shifting easily.

2.2 User test

Through the interviews, the current user's habit and major problems of cycling backpack were identified. To further address the issues of heat ventilation, a user test was conducted with two male participants. Participants had a height of 1.72m and 1.85m and a weight of 64kg and 90kg respectively. Specifically, this user test was aimed to investigate the severity of backpack thermal issues and identify the possible sweating zones when riding with a backpack. In the test, participants were asked to cycle for 15 minutes with an ordinary backpack in an outdoor environment, with a temperature around 25℃ and humidity around 60%. In the same time, they were requested to do several times of head turning to check the traffic situation. The whole process was video recorded.

Several comfort issues were identified based on the test. Thermal discomfort was frequently reported by the participants. It was found that a lot of sweat was accumulated around the back area during the test. As shown in Fig.1, the main sweating areas included the shoulder part that in contact with backpack straps, the upper center of the back, as well as the middle to lower part of the back. In addition, we also found that the backpack could not adequately support flexible body movement. Participants indicated that it was difficult to twist the body or turn the head when cycling.

Fig. 1. Sweating zones identified after 15-minutes cycling.

3 Design process and prototype development

Results of the user research provided valid data for design concept and prototype development. It was found that the issues of thermal comfort and sweating were the most pronounced problem for riders with backpacks. Accordingly, the design criteria were identified. The backpack design was firstly aimed to provide greater thermal comfort for riders with backpacks through better heat ventilation design. In addition, it aimed to enhance the body movement by providing better support for the backpack. Following the design criteria, an initial concept of ‘hard shell’ was developed. By adding a ‘hard shell’ supporting to the backpack, an air gap was created between the back and backpack and the contact area was decreased. In this way, the airflow will be greatly improved, and the heat evaporation will be largely enhanced. Also, the ‘hard shell’ was iteratively designed in order to fit the body shape while users were riding a bicycle, which is expected to better support their body movement during the process. The whole concept design is shown in Fig.2.

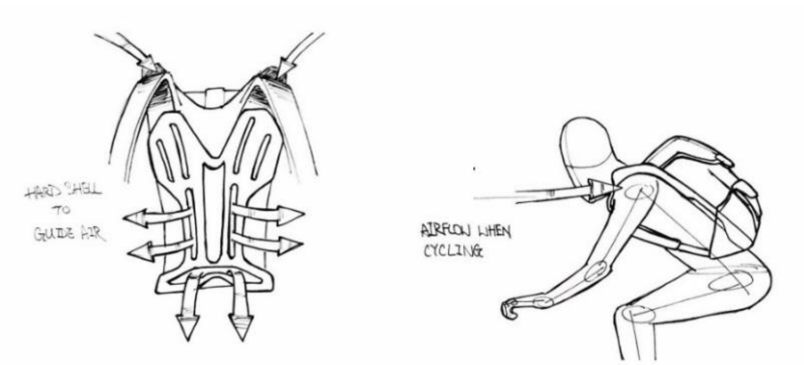

Fig. 2. Concept design demonstrating the air flow through backpack support.

Based on the concept design, an experimental prototype of the backpack shell was developed. The shape, size, and surface of the prototype were iteratively tested and modified. Fig.3. showed three stages of prototype model development during the iterative design process. In the first stage, a plain shell was developed. It was found that the shell could not provide a stable air gap for the backpack and the shape was not fit for the body surface especially the shoulder part. In the second version of the prototype, we added several supporting blocks to the shell and refined its shape to better fit the body surface. After detailed modification, a final prototype was developed. Details are shown in Fig.4. For this backpack, the air could smoothly flow into the area between the human body and the backpack from the upper part of the shell and then go through the blocks gap inside the area between body and backpack. Thus the airflow can be largely improved, and the heat release can be accelerated. In addition, the "X" shape design makes that hard shell could be easily supported only by several areas of the back. The parts of neck, shoulder, and waist could move more smoothly and efficiently, which will further enhance the body movement.

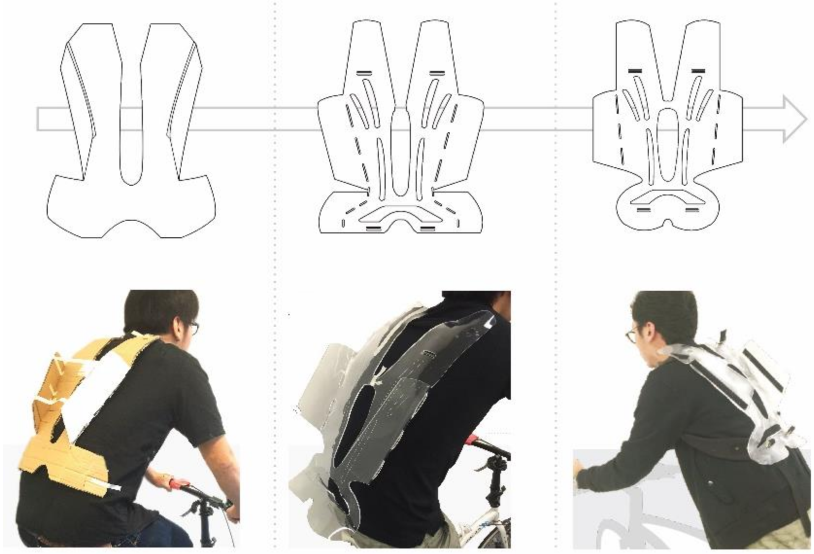

Fig. 3. The process of prototype development

Fig. 4. Final prototype development

4 Evaluation of ventilation backpack design

4.1 Experiment design

An experiment was used to test the effectiveness of backpack ventilation. One participant aged 20 years old, with a height of 172cm and a weight of 64kg, was recruited for this experimental test. Although this backpack design was designed mainly for cycling backpack, we also considered other situations such as walking. Thus, four tasks were planned with a 2 (exercise conditions of walking and cycling) × 2 (backpacks with and without ventilation design) factorial design. Based on the data from user research, we chose to carry the same contents as people would usually take with their backpack. Thus, a backpack with a weight of 2.6 kg was utilized. It contained a jacket, a water bottle, an umbrella, and some personal accessories, which was approximately equal to 4% of participant's body weight.

There were four tests totally in the experiment, including walking and cycling using the backpack without ventilation design, as well as walking and cycling using the backpack with ventilation design. In each test, the participant was required to walk or cycle with the backpack for 20 minutes. The participant was asked to complete the four tests one by one. Between each of the test, 60 minutes at least were given to the participant to rest to avoid fatigue. The whole experiment was conducted in an outdoor environment with the temperature ranged from 25℃ to 29℃, the air velocity ranged from 11km/s to 15km/s, and the humidity ranging from 55% to 65%, which represented an average outdoor thermal environment of Hong Kong in summertime [22].

After each test, skin temperatures of the back were measured using the FLIR E33 Infrared Camera, a Thermoval duo scan thermometer. Skin temperature was measured because it has been widely applied as an indicator of thermal comfort in ergonomics and design field [23-24]. The infrared thermography was commonly utilized in skin temperature detection and was easy-to-use and nonintrusive for users. The results of temperature distributions were used to evaluate the effectiveness of ventilation design under different situations. Additionally, the participant was asked about how the backpack design fit the body movement during the whole process.

4.2 Analysis and result

The plots of skin temperature distributions under four conditions are shown in Fig.5. In the walking condition, no significant difference was found in terms of the maximum back skin temperature between the situations with and without ventilation design. Nevertheless, the skin temperatures of the left and right sides of the middle to lower back decreased when the participant used the ventilation backpack. As for the cycling condition, a significant difference of skin temperatures was found between the situations with and without ventilation design. Results showed that skin temperatures of the back were significantly decreased when carrying ventilation backpack, with the maximum temperature decreasing from 36.0℃ to 33.8℃. In addition, the participant indicated that the backpack design could better support their body movement. During the test, he could easily twist the body and turn the head when riding the bicycle.

The results indicated that, by creating an air gap and reducing the contact area between the back and backpacks, skin temperatures of the back were largely decreased when the participant was riding a bicycle. However, no significant temperature decrease was detected in the situation of walking exercise when carrying the ventilation backpack. The reason can be explained by some of the previous studies [16, 25]. It was found that the air gap could help in reducing thermal insulation, especially during body motion or under windy conditions. Thus, as expected, when people are riding bicycles, the air gap of the ventilation backpack could guide the air into the area between user's back and the backpack more effectively because of the increased wind speed. In this way, the heat and sweat evaporation is largely improved for riders who need to carry loads.

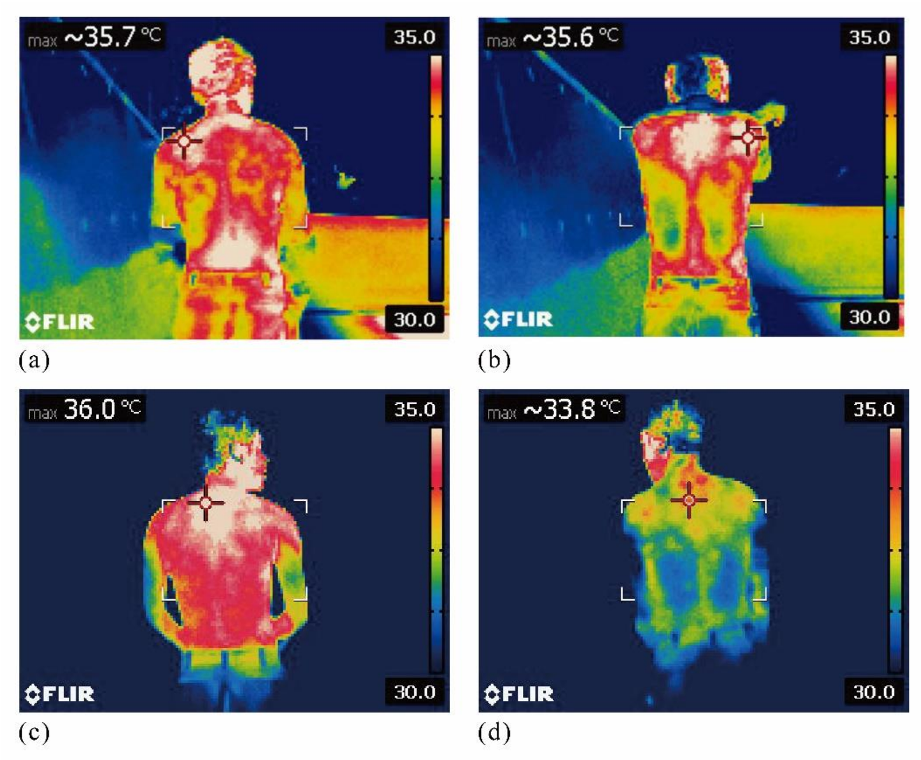

Fig. 5. Back temperature distribution for each condition: (a) condition of walking exercise with an ordinary backpack; (b) condition of walking exercise with ventilation backpack; (c) condition of cycling exercise with an ordinary backpack; (d) condition of cycling exercise with ventilation backpack.

5 Conclusion

Plenty of studies have tried to improve backpack comfort in several ways such as reducing load weights and balancing load distributions. However, few studies have investigated the issues related to thermal comfort, which is especially important for outdoor exercises with backpacks.

This study mainly focused on an ergonomic redesign of a backpack with the objectives of improving the user experience for riders who need to carry backpacks by enabling better heat ventilation and body support. It is comprised of several stages, including problem identification, objectives development, design concept, prototype development and experimental evaluation. Sufficient evidence was generated from each stage. Specifically, in order to better understand the ergonomic issues related to cycling backpacks, interviews were first conducted. The issue of thermal discomfort was identified as the major problem that needed to be solved. Following, user test was further completed to investigate the severity of heat stress issues. The main sweating zones were also identified. These results helped in formulating the design criteria of ventilation backpack design. The prototypes were then developed and modified iteratively. The final prototype was evaluated by the experiment.

In particular, four conditions of backpack usage were examined in the experiment. Skin temperatures of the back were detected by infrared technology. The surface temperature distributions were monitored after each test. As expected, the results showed that the adding of the shell creates an air gap between the back and the backpack, which largely improved the airflow and accelerated the heat release. The ventilation backpack could effectively decrease the back temperatures when the participant was riding a bicycle. Results of the current study can be used in backpack design towards designing for greater thermal comfort. By improving the backpack thermal comfort, it can help in maintaining high-quality outdoor activities, which would further encourage people to take part in more outdoor exercises and adopt more sustainable commuting strategies.

There are also some limitations to the current study. Firstly, this study was planned as the first phase to investigate the issues of thermal comfort for backpack use, in which the number of participants was limited. Further study would recruit more participants to uncover more details related to thermal issues. Secondly, in order to simulate the realistic situation, we conducted the experiment in an outdoor environment. Researchers from other regions need to be careful when applying these results because of climatic differences. In the future study, the experiment can be conducted in a controlled laboratory environment. The temperature, humidity, and air velocity would be settled at different levels in order to investigate possible influences of different factors.

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