The Impacts of the Airflow System in the Shoe on the Foot Environment

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Abstract. Army soldiers stationed in frigid regions are highly susceptible to foot health problems, partly due to the constant sweating and moisture inside closed military boots. Winter military boots on the market lack attention to dehumidification and ventilation. To address these issues, we propose a boot system that includes a dynamic airflow system integrated into the core of the shoe midsole. This system works on the principle that the user's heel naturally squeezes the airbag under the heel during movement, thus creating an air pressure difference that drives the air movement inside the shoe. Through the experiments on the product prototype, it was found that this system allows the temperature and humidity of the foot to drop significantly within the shoe and boot environment, improving foot comfort and reducing the generation of sweat on foot. What can be expected is that after soldiers wear this shoe and boot product, the moist air inside the shoe can be continuously exported out of the shoe during dynamic training while also avoiding the consumption of external energy, keeping the foot dry and comfortable, and reducing foot injuries. And this system has the potential to be extended to a broader civilian market.

Keywords: Dynamic airflow; ventilation; foot condition; system design; industrial design.

1. Introduction

Sweating is part of the human thermoregulatory mechanism, and there are different numbers of sweat glands in various parts of the body [1]. The human foot has very sophisticated sweat glands, about 250,000 in all, with an estimated average of 600 sweat glands per square centimetre. Therefore, it is easy for most people to sweat on their feet [2].

A great number of troops are currently active in frigid regions around the globe, where the environment is harsh, and the climate is atrocious, making it challenging for the Army units stationed there to train and conduct operations such as skiing, shooting, camping and hiking [3, 4]. The foot injuries incurred during winter training are frequently seen, including cutaneous foot injuries (blister, abrasions, and hot spots) and traumatic injuries (acute ligament sprains and fractures) [5-7].

Winter boots are a great companion for soldiers training in frigid areas. Generally, these winter boots are bulky and have isolation and sealing properties to prevent limited heat loss [8]. However, they are also poorly ventilated. Soldiers' feet generate heat during training or operations, which builds up in the shoe and causes the foot to sweat profusely, resulting in a humid environment. The moist environment poses health risks for Soldiers, and some are distraught. At the end of a campaign, the damp, warm environment of shoes and boots can turn into a wet, cold environment, so trench foot and frostbite abound. It is also easy to overlook that a wet environment tends to affect the friction between the foot and sock, and this change in friction can easily lead to unusual sliding of the foot, which can cause health hazards, such as sprains.

Inspired by the principle of exhaust fans [9], a dynamic airflow system for insulating shoe and boot sweating environments is proposed. During the user's movement, the heel produces a natural squeeze on the built-in airbag, which accordingly produces an air pressure difference that sucks the hot and humid air out of the shoe to achieve the goal of reducing heat and humidity inside the shoe. In the meantime, military personnel in frigid areas are more difficult to carry a stable source of energy, such as batteries in a cold environment, it is difficult to maintain stable performance, so the design of this system does not require external energy input.

The design of military boots is not a single functional design but needs to consider ergonomics, aesthetics, structure, material science, and humanized design as a way to meet diversified needs [10].

This research aims to reduce the potential for injury and illness caused by soldiers' inability to drain foot sweat during cold weather training. At the same time, this unique design of the airflow system in shoes has the potential to be extended to civilian products, such as hiking and outdoor shoes. This solution could improve the health of people's feet to a certain extent by saving them from the accumulation of foot sweat.

2. Methodology

A simulated experiment was created to test the efficiency of the built-in airflow system. This experiment simulated the condition of feet heated after training or actions.

2.1. Materials in pre-experiment

2.1.1 Interviews

An active-duty Army soldier and a retired Army soldier, both of whom served in high latitude cold regions, participated in the interview. Observations from interviews: 1. The ground condition could be very slippery and hard. 2. The feet are easy to get sweaty when training. 3. The foot condition really bothers the soldiers. 4. The sole of boots is thick, easy to twist ankle. 5. The sweat generated from bottom to top. 6. The campfire are not allowed to use in battlefields to prevent exposure. 7. The power supply is not stable in battlefields so heating system is limited.

2.1.2 Concept design

The final design is a light cool gray tone overall, designed to blend in with the snowy environment. It breaks away from the conventional military boot look and has a certain sense of fashion while retaining a sense of ruggedness. The sole uses a combination of large grain and small grain shades to ensure good slip resistance. The inner outsole of the toe part is turned up to provide some protection for the toes. To make it easy for users to put on and take off, the new design features two reliable buckles and a Velcro strap, and these also give the overall look a more rhythmic feel. The tongue-less design also ensures ease of donning and doffing and the simplicity of the shoe's upper structure. The heart of the design is the airflow system in the midsole. A thin duct in the form of a tree branch connects the air vents in the forefoot of the insole to the elastic air bladder in the rearfoot. From the flexible airbag, another thick tube extends along the inside of the upper to an air valve at the neck of the foot. This creates a pathway for the air inside the shoe and the air outside the shoe. The elastic airbag at the heel has a built-in fiber, and when the user performs dynamic movements, the heel will continuously squeeze the airbag to produce deformation, and the deformation of the airbag will generate negative air pressure and promote airflow in the airflow system. At this time through the adjustment of the air valve to change the airflow inward or outward flow direction. (The air valve is a one-way valve, that is, the airflow can only be one-way flow)



Figure 1. Concept rendering

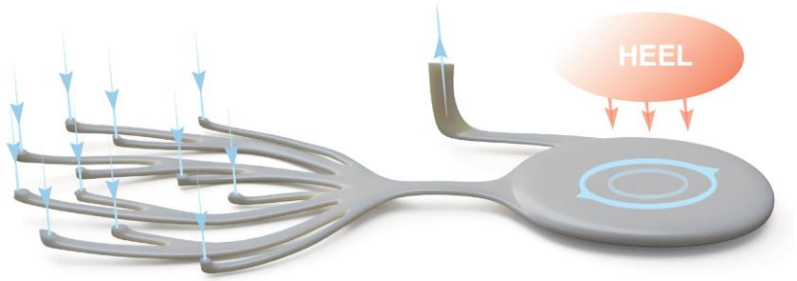


Figure 2. Dynamic airflow system

2.2. Functional prototype making

A functional prototype was built to do the experiments, which integrates an airflow system. This prototype creates a insulate environment inside, simulating natural boot conditions. The air pump part is placed outside, which makes it more convenient to activate. Two one-way valves were installed at both ends of the airbag pump to ensure that the direction of airflow kept from inside to outside. A thermometer and hygrometer are integrated into the vamp for easy readings at any point in time.



Figure 3. Functional prototype

2.3. Participants

20 adult participants were selected to do the experiments, including 14 males and 6 females. As planned, these participants would do two rounds of ten-minute exercise (running) to make feet generate heat, simulating the condition of basic military training. On this premise, the experiment was conducted.

2.4. Experimental design

2.4.1 Independent variable.

The independent variable is the passed time after participants put their feet into the prototype. This experiment limits the time-*independent* variable to 10 minutes. From 0 to 10 minutes, the data would be recorded every minute.

2.4.2 Dependent variable.

The dependent variables are the temperature and the humidity inside the prototype after participants put their feet into it. Temperature and humidity are two important factors that can show the condition of the feet environment. Sweaty foot mostly creates higher temperature and humidity in an insulated shoe environment. Therefore, these two factors can help to evaluate the sweaty condition and comfort level. Through the integrated thermometer and hygrometer, dependent variables are intuitive to record.

The important thing is that the change of dependent variables depends on the physical functions of different participants. Everyone possesses various physical features, which means they would have different foot conditions after exercise. The data range would be vast.

2.4.3 Control variable.

To test the efficiency of the airflow system, two groups were set. One is the blank group, and the other one is the control group. In *the* blank group, the airflow system was deactivated (not pressing the air pump), and the natural changes in the temperature and humidity inside the prototype would be recorded. In the control group, the airflow system was activated (keeping pressing the air pump during the experiment), *and* the changes in the temperature and the humidity inside the prototype would be recorded. After the experiment, comparing the data collections of the blank group and control group would help to evaluate the airflow efficiency.

2.5. Procedure

Before the experiment, all participants did a ten-minute exercise (jogging) to simulate basic military training. Then the participants were asked to put their feet inside the prototype immediately to reduce heat loss. This process would make their feet generate heat and sweat.

For the blank group, the airflow system was deactivated (not pressing the air pump), and the natural changes in the temperature and humidity inside the prototype would be recorded. For the control group, the airflow system was activated (keeping pressing the air pump during the experiment), and the changes in the temperature and humidity inside the prototype would be recorded.

Between the participants doing the blank group experiment and the control group experiment, they were asked to wait for 40 minutes to let their feet back to their original status. Between every experiment, the prototype needed 40 minutes of the fan blowing to let the temperature and humidity inside it back to the initial level.

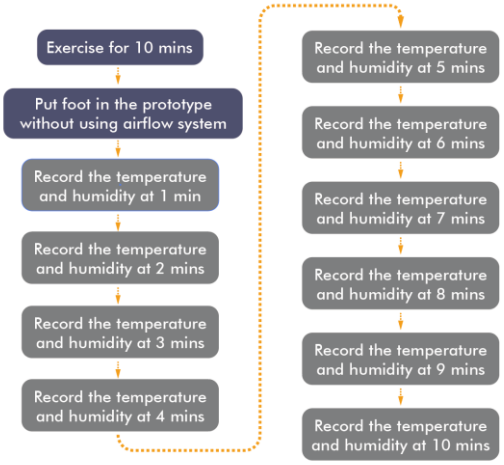


Figure 4. Procedure for the blank group

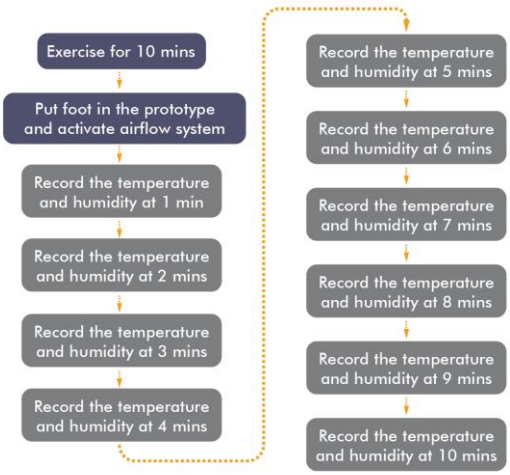


Figure 5. Procedure for the control group

2.6. Data analysis

Twenty sets of experimental data were obtained for the blank and control groups separately. Because the changes in the data were continuous on the time scale, line graphs were chosen for data analysis.

To obtain the trend of the overall dependent variable, twenty line graphs of twenty sets of data are overlaid in one chart. This way, a curve of variation patterns can be obtained within a specific range. The median curve is used here for more accuracy.

Finally, the efficiency of the airflow system could be evaluated by comparing the temperature change curve and humidity change curve of the blank and control groups.

3. Results

For the blank group, 20 sets of temperature variation data and 20 sets of humidity variation data were separately made into line graphs (see Figure 6 and 8). Based on line graphs, it can be found that the temperature showed a rising trend, and the rate of increase gradually slowed down. Humidity rises rapidly in the first 1-3 minutes, and then the rate of growth slows down rapidly, but the humidity remains at a high level.

For the control group, 20 sets of temperature variation data and 20 sets of humidity variation data were separately made into line graphs (see Figure 7 and 9). The changing pattern of temperature and humidity was consistent with that of the blank group, but the increase in temperature and humidity was lower than that of the blank group.

Curves of median were created to analyse the changing trends. The median temperature curves of the two experimental groups were combined in one graph to obtain Figure 10; the median humidity curves of the two experimental groups were combined in one graph to obtain Figure 11.

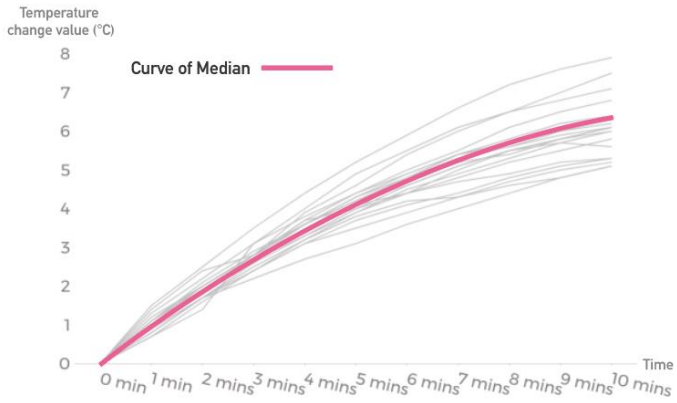


Figure 6. Temperature change values for blank group

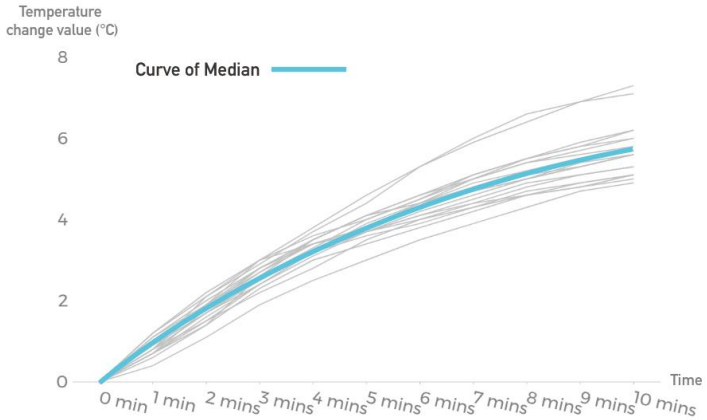


Figure 7. Temperature change values for control group

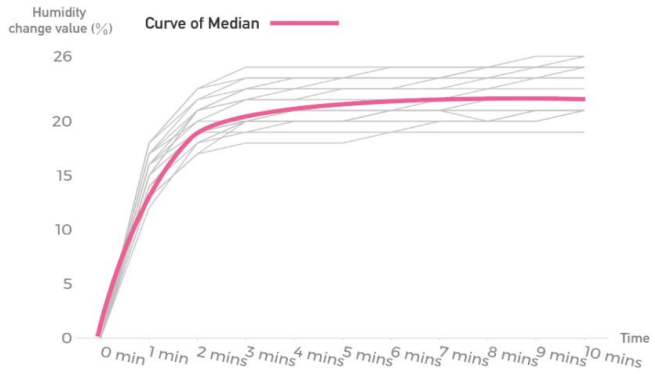


Figure 8. Humidity change values for blank group

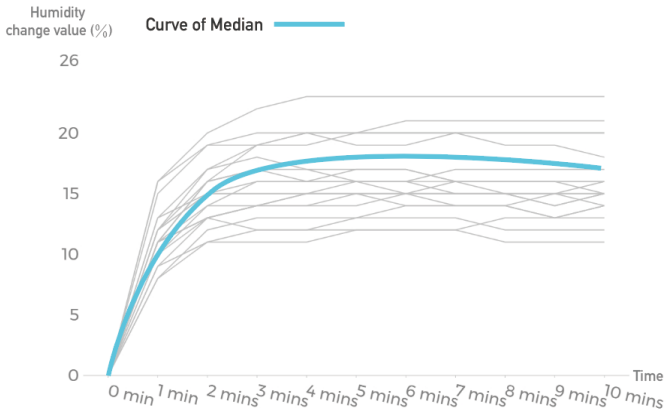


Figure 9. Humidity change values for control group

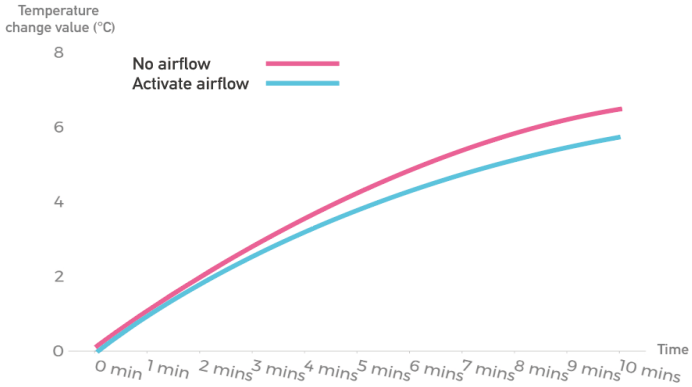


Figure 10. Median curves comparison of temperature change values

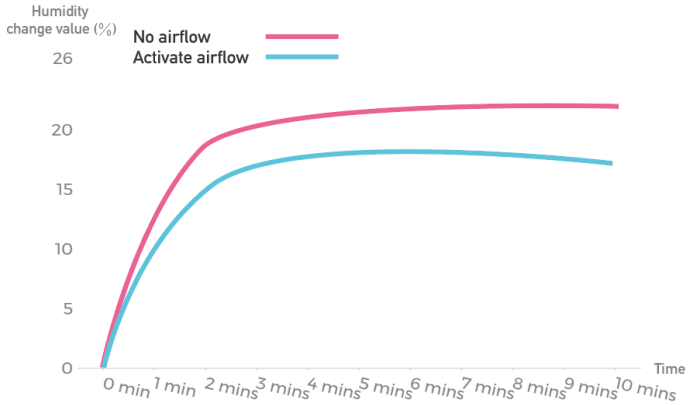


Figure 11. Median curves comparison of humidity change values

4. Conclusion

Some uncertainties may affect the experimental results during this experiment. i) When performing the exercise, different participants had different running speeds, and the exercise intensity could not be quantified. Some participants were physically fit and exercised with high intensity. Still, some participants were limited by their physical condition and exercised with less intensity, which may lead to some extreme data. ii) When using the airflow system repeatedly squeezing the airbag, the squeezing intensity and speed cannot be quantified. The squeezing pace may be too fast or too slow and cause errors. iii) Participants had different foot sizes, while the prototype size was fixed. Some participants' feet matched the prototype size, and their feet could fill the entire space inside the shoe. Some participants' feet do not match the prototype size, which may result in extra space inside the shoe and may affect the data measurement accuracy.

When conducting further research, the intensity of the exercise should be quantified before doing the test, such as jogging at the same speed, to keep this factor as stable as possible. Secondly, the intensity and speed of airbag squeezing should be quantified, and the number of squeezing within each minute should be controlled to keep the intensity stable. Finally, the participants should be selected with the foot size matching the prototype as much as possible to ensure that there is no extra space within the prototype to affect the heat transfer and to ensure the stability of the data reading.

By observing the median curve, it was found that the airflow system reduced the increase in temperature over time to some extent, and the increase in temperature at the tenth minute was reduced by one degree Celsius compared to the blank group. During the time increase of humidity, the airflow system reduced the rise in humidity, and the humidity tended to decrease after 8 minutes under the action of the airflow system, and the increase of humidity decreased by 7% at the tenth minute compared with the blank group. The reduction in temperature and humidity growth is not significant, probably because the airflow per unit time through the check valve is small. However, the decrease in temperature and humidity growth indicates that this airflow system is effective in removing heat and moist air from the shoe at a specific rate, thus improving the foot environment to some extent and reducing sweat production. This solution has the potential to be optimized and the potential to be applied to products with better pervasiveness.

References

[1] Li Y and Wong ASW 2006 *Clothing Biosensory Engineering* (Cambridge: Woodhead Publishing)

[2] LaFee S 2017 Shoeless Glow https://health.ucsd.edu/news/features/pages/2017-02-24-listicle-feet-facts.aspx

[3] Vergun D 2017 Alaska's Extreme Cold Tests Soldiers, Equipment https://www.defense.gov/News/News-Stories/Article/Article/1090533/alaskas-extreme-cold-tests-soldiers-equipment/

[4] Decker S 2017 Cold Weather Training-Embrace the Cold https://www.army.mil/article/194712/

[5] Reynolds K, Williams J, Miller C, Mathis A and Dettori J 2000 Injuries and Risk Factors in an 18-Day Marine Winter Mountain Training Exercise *Military Medicine* **165** 905

[6] Esther CL, Gabriel GN, Raquel SR and Alfonso MN 2022 The influence of sock composition on the appearance of foot blisters in hikers *J Tissue Viability* **31** 315

[7] Kirkham S, Lam S, Nester C and Hashmi F 2014 The effect of hydration on the risk of friction blister formation on the heel of the foot *Skin Res Technol* **20** 246

[8] White MD, Gnatiuk EA and Cartwright J 2019 Limited Thermal Protection of Canadian Military Winter Garments in Extreme Cold Conditions *International Journal of Sports Physiology and Performance* **14**

[9] Calabrese SR 2003 Practical Controls (New York: River Publisher) chapter 15 pp 281-291

[10] Ikoro AO, Garba DKA and Jacob O 2020 Design and Production of Combat Boot Soles for Military Applications *American Journal of Engineering Research* **9** 149-164