Basic Studies on Thermal Ergonomics of Clothing for Human Comfort and Performance

胡, 少営

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氏　　名　：胡 少営

論 文 名　：Basic Studies on Thermal Ergonomics of Clothing for Human Comfort and Performance（人間の快適性とパフォーマンスのための衣服の温熱人間工学に関する基礎研究）

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Summary

People live or work in various temperature environments, whereas human comfort and performance may change with varying air temperatures. Indoor discomfort and excessive energy use have been reported worldwide due to air conditioning over-cooling or over-heating. Clothing is considered to be a most effective and energy-saving adjustment for occupants to adapt to thermal environments. Thus, this thesis investigated thermal ergonomics of clothing for human comfort and performance by focusing on the effects of clothing and air temperature on participants' seasonal adaptive characteristics, comfort, fatigue, human performance, and physiological responses based on the related models (e.g., PMV and adaptive comfort models, the extended-U model). A series of field studies across a year and two laboratory studies were conducted using Japanese college students as participants in a systematic way.

Firstly, in field studies across a year (Chapter 2), participants' seasonal adaptive characteristics of clothing and thermal comfort by gender were investigated. The effects of air temperature were reflected by seasonal variation and summer indoor-outdoor difference. Significant seasonal variation was observed in clothing categories or types, amount, and insulation by gender, although some clothing types were stable. Obvious seasonal effects existed in indoor TS, PF, and AP despite participants being in or close to comfortable conditions, especially compared with summer, which showed short-period seasonal stability. The results also showed gender and local differences in clothing and thermal comfort. Clothing and thermal comfort influenced each other by gender to adapt to thermal conditions. These findings suggested that the effects of combinations of clothing and temperature on participants' performance, comfort, and related physiological responses needed to be examined when under laboratory conditions; moreover, gender and local differences should be taken into account.

Secondly, in a laboratory study (Chapter 3), I explored the effects of clothing and air temperature combinations on productivity, comfort, and physiological responses in male participants, who were exposed to six combinations of clothing (0.3 clo and 0.9 clo) and air temperature (16 ℃, 26 ℃, and 36 ℃). It was found that cold exposure (especially when combined with lower clothing levels) undermined manual motor performance, but likely

increased the sustained attention levels. Calculation test performance tended to be affected by air temperature (cold or neutral) and clothing at the beginning of the test. Under cold conditions, participants felt more alert and less uncomfortable compared to hot conditions, and showed more instability in 0.3 clo than 0.9 clo. Furthermore, air temperature affected comfort and clothing microclimate. There were obvious clothing effects and local differences for comfort, especially under cold conditions (e.g., TS, TC, CF, and AP). Clothing tended to increase the T_{clo} but may decrease the RH_m during cold exposure. Both cold exposure and higher clothing level during heat exposure increased blood pressure. Body temperature, particularly skin temperature, increased with increasing air temperature and was significantly influenced by clothing insulation during cold exposure. Accordingly, it was recommended that cognitive performance and physiological responses during cold exposure were further examined.

Thirdly, in a further laboratory study (Chapter 4), the effects of clothing on cognitive performance, perceptions, and physiological responses at 16 ℃ were examined, especially considering gender and local (upper-lower) difference. Although the results showed gender similarity in cognitive functions and emotions, females tended to exhibit lower accuracy for d2 test EO performance. Mildly cold exposure significantly increased RAS attention levels but decreased thermal comfort levels. Compared with other clothing conditions, 0.6 clo-U showed higher sustained attentional performance and calculation test performance. Wearing more clothing decreased strain levels, and increased sleepiness, relaxation, and thermal comfort levels. The effects of clothing on performance were attributed to the perceptions and physiological responses. Compared with females, males exhibited higher P300 latencies, LF/HF, and MAP (especially in FF). Furthermore, females showed lower skin temperatures at trunk and proximal limbs than males because of physical and physiological characteristics. Although no clothing effect was observed in neurophysiological and cardiovascular responses, 0.6 clo and cold exposure tended to induce a higher AAC and a lower P300 latency, respectively. However, T_{sk} increased with increasing thermal insulation of clothing, especially the upper-body clothing, and the upper-lower body difference existed in the clothing effect on thermoregulation.

In conclusion, despite some limitations, this thesis provides novel insight into thermal ergonomics of clothing and especially demonstrated the effects of clothing and air temperature on human comfort and performance, considering related physiological responses, gender and local differences. However, there are still some incomplete answers as well as unidentified effects of clothing on human comfort and performance deserving further investigation. Finally, the interpretation of the findings from this study to environmental ergonomics contributes to application in human comfort, workplace productivity, and clothing design.