Humans in Hot Environments : A Brief Introduction of Studies of Environmental Physiology in Japan

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ABSTRACT

This is a brief introduction to environmental physiology studied in Japan. This description is based on a chapter in a book by the late Dr. Hisato Yoshimura (1907-1990) entitled "Man in Stressful Environments, Thermal and Work Physiology", The aim of this article is to introduce research on acclimatization of humans to hot environments. Therefore an attempt has been made to include the physiology of sweating, temperature regulation, seasonal variation of physiological functions, and methods of analyzing tolerance to hot environments.

Key words : climatic adaptation, cold stress, seasonal variation, sweating, thermal tolerance

1. INTRODUCTION

This article is a brief introduction of the development of studies of thermal physiology in Japan which has been based on a chapter in a book by the late Dr. Hisato Yoshimura (1907-1990) entitled "Man in Stressful Environments, Thermal and Work Physiology" (Shiraki and Yousef, 1987). Although Yoshimura described many aspects of studies of the environmental physiology in Japan (Yoshimura, 1987), only selected topics of thermal physiology will be introduced in this article. The foreword of his book says : "The book has been published as a tribute to Yoshimura for his brilliant record of achievements in environmental physiology. Yoshimura has been in the forefront not only as a well-known researcher and excellent teacher but also as an organizer and leader of several international programs and expeditions to various climatic regions."

The island country of Japan lies along the east coast of the Asian continent, extending from subtropical (Okinawa) to sub-arctic (Hokkaido) regions. The shores of the Japanese islands are fronted by two main ocean currents, i.e., the warm Black Current along the southern shores facing the south Pacific Ocean, and the cold Kuril Current along the shores of Hokkaido and the northeast coast of the main island. Therefore, the climate of Japan changes considerably through the four seasons. Briefly, the Japanese climate overall is characterized by high temperatures with high humidity in summer and low temperatures with low humidity in winter. Both the adjustment to a hot climate in summer from a cold winter and the large area of rugged mountains on the islands influence the living patterns and physiological functions of the inhabitants. A short term adaptation to heat and cold is inevitable among inhabitants from season to season. In this paper, emphasis is given to the development and history of thermal physiology in Japan.

2. HISTORICAL REVIEW OF CLIMATIC PHYSIOLOGY WITH SPECIAL REFERENCE TO BODY TEMPERATURE REGULATION

(1) Physiology of Human Sweating

The father of Japanese thermal physiology was Y. Kuno. He began studying the physiology of human sweating in Mukden (Shenyang), Manchuria, devising a new method of continuously measuring sweat rate on the skin. In collaboration with K. Ogata, he found that sweating can be classified into two types, i.e., thermal sweating and mental sweating. The former is induced in response to heat exposure, while the latter is produced in response to psychological stress. Kuno (1934) also found the presence of entirely inactive sweat glands among those distributed over the skin.

Furthermore, he studied the development of secretory activity of sweat glands together with their innervation and humoral control. Kuno explained the effects of various factors on the appearance of sweating by the concept of ability to perspire. This concept underlines sweat gland activity, excitability of the sweating center and the coordination of sweating reflex as initiated by heat and/or psychological stresses. The physiological significance of thermal sweating in body temperature regulation and its impact on water and salt metabolism in body fluids were systematically investigated. Kuno's work in South Manchuria was published in a monograph which made him famous world-wide (Kuno, 1934). Leaving Manchuria, he first studied with Dr. S. Itoh between 1948 and 1952, and found that heat acclimatization resulted in a reduced concentration of sweat salt. This finding led him to study homeostatic mechanisms of water and salts during heat acclimatization, especially in tropical countries. The story of the physiology of human perspiration in relation to body temperature regulation and to body fluid homeostasis was published in a monograph (Kuno, 1956).

(2) Physiology of Cold Stress

Although the physiology of cold stress is not the major concern of this article, an introductory description will help the readers' understanding of the seasonal variation of physiological functions of humans, which is the major concern. Inspired by Kuno's brilliant work on human sweating, Shoji went to Manchuria in 1937 and started a series of studies with Ogata between 1937 and 1940 on physiological responses of man to extreme cold (−20 to −30°C). Shoji made three winter trips by 1940, and Ogata continued the work until the end of World War II. These studies provided the foundation for the study of the physiology of cold stress in Japan. Ogata published his findings in a monograph (Ogata, 1949). Additional studies on the physiology of cold were made regarding the role of shivering, blood redistribution, respiration, muscle fatigue, and the central nervous system on cold tolerance (Ogata, 1960 ; Shoji, 1942 ; Yanagi, 1939). During the war Yoshimura studied the prevention of frostbite at a military institution and devised a method for estimating the ability to resist frostbite, the frostbite resistance index, by monitoring the cold-induced vasodilating reaction (temperature hunting) of a fingertip immersed in ice water (0°C). With this method, comparison of ability to resist frostbite was made among various ethnic groups living in Manchuria and the data confirmed that resistance to frostbite was largely dependent upon the individual's exposure effect to cold (Yoshimura & Iida, 1950, 1952).

(3) Studies on Seasonal Variations of Physiological Functions

In 1946 Kuno organized and chaired a nationwide cooperative research project team of environmental physiologists, and the team continued until 1953. The aim of this project team was to investigate physiological reactions to changes of the climate and seasons. This group consisted of 30 regular members who were working in various institutions including physiology, hygiene, occupational health, etc. The activities and many of the accomplishments were published in a monograph "Essential Problems in Climatic Physiology" in 1960 (Yoshimura, 1960). The following summaries represent the major contributions in the field of climatic physiology, which are of the major concern of this article.

1) Skin Pressure Reflex

Takagi (1960) found that an exertion of mechanical pressure on the skin induced an inhibition of sweating on the side where pressure was applied, while enhancing sweating on the opposite side of the body. This finding clearly solved an enigma in thermal sweating which Kuno had experienced, i.e., an increase in sweating on the upper part of the body while lying, and its reduction on the lower side pressed against the bed.

2) Seasonal Variation of Activity Level of the Autonomic Nervous System

Harashima (1953) observed seasonal variation in activity of the autonomic nervous system. He demonstrated that sympathetic nerve activity increased in winter, and decreased in summer, while activities of the parasympathetic nervous system showed the opposite seasonal changes.

3) Seasonal Variation in Body Fluids and the Mechanism of Acclimatization

Yoshimura (1960, 1964) and his colleagues (Yoshimura, 1960, 1964) found a decrease in ionic concentration of Na and osmolality in extra cellular fluid (ECF) in summer and an increase in winter, which was attributable to an ECF expansion in summer and shrinkage in winter. The total content of Na in ECF increased in summer, while it decreased in winter. Seasonal changes in K concentration were in the opposite direction to that of Na. These seasonal changes were found to be linked with changes in plasma level of antidiuretic hormone and aldosterone.

4) Seasonal Variation of Basal Metabolism in Japanese

Seasonal variation of basal metabolism (BM), high in winter and low in summer, was confirmed in Japanese subjects (Yoshimura, 1960). These seasonal changes were verified to be linked with thyroid function. These findings suggest that acclimatization is the function of an integrative network of the autonomic nervous system and the endocrine system. Hori *et al.* (1977) compared basal metabolic rates among differently heat-acclimatized peoples including inborn tropical-acclimatized Thai and relatively short-acclimatized Japanese in summer. They plotted the basal metabolism of young male subjects against the monthly mean ambient temperature of various ethnic groups, including Japanese (Ogata & Sasaki, 1975), Korean (Kim, 1965), Indian (Malhotra *et al.*, 1960), residents of Okinawa, a subtropical zone of Japan (Nohara *et al.*, 1974), and Canadian (Yoshimuraet al., 1966). The basal metabolism had a linear correlation with the monthly mean ambient temperature between temperatures of 10°C and 27°C except for that of the Canadians (Fig. 1). According to the linear equation, the basal metabolism decreases by 2.1 kcal/m^2/h as the ambient temperature increases by 10°C. The values for Canadians in this figure deviate upward from the 95% confidence line. These authors postulated that the higher basal metabolism of Canadians compared to the other peoples was because of a higher intake of fat (42% of total caloric intake, Yoshimura *et al.*, 1966) than people in Asia for whom rice is the main food, a high carbohydrate diet (about 70% of total caloric intake, Yoshimura *et al.*, 1966 ; Valyasevi *et*

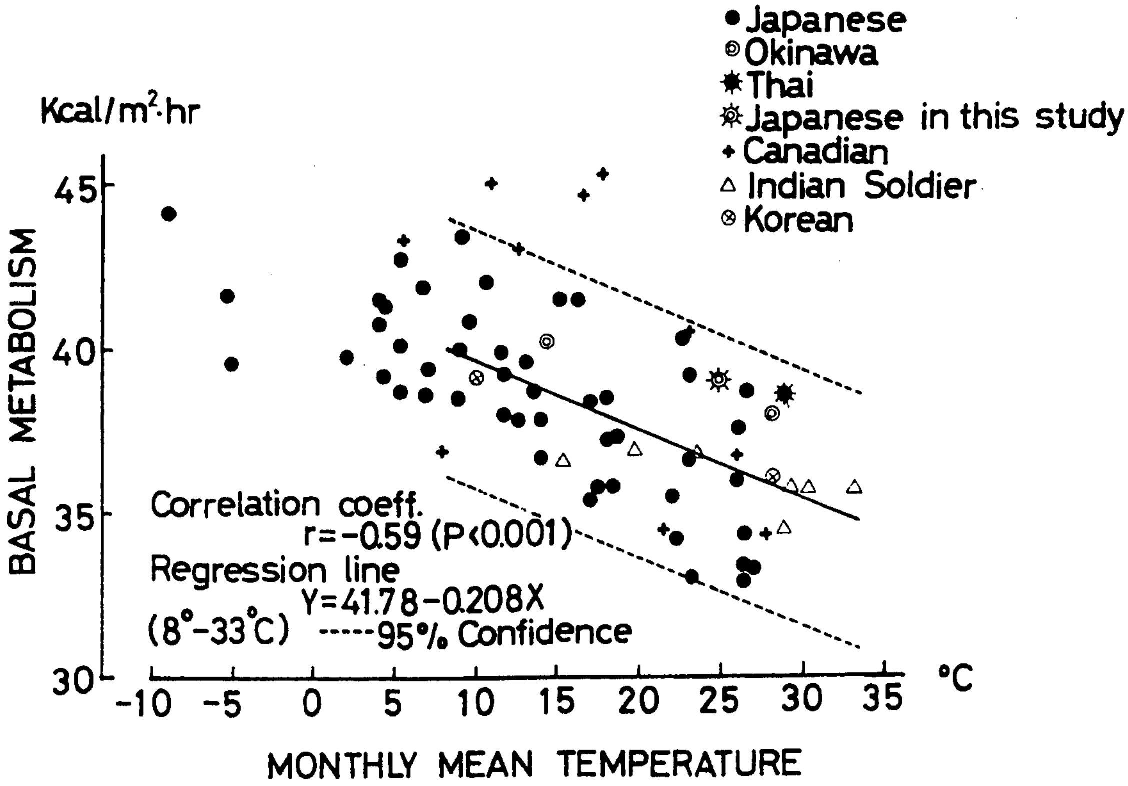

Fig. 1 Climatic effect on group means of basal metabolism in Asia. Adopted from Hori *et al.*, 1977.

al., 1967). They have speculated, based on the study of Yoshimura *et al.* (1966), that high intake of fat inhibits reduction of the resting metabolic rate and thyroid activity which occurs during the process of normal heat acclimatization, while a high intake of carbohydrates has the opposite effect on these functions. For people in a hot environment, reduction of the metabolic rate will be advantageous because metabolic heat production is dissipated to the environment at the rate of its production to maintain constant body temperature. Thus, lowered basal metabolism of the subject living in a hot environment is considered an important physiological adaptation during acclimatization to the environment. In addition to the lowered heat production, Thai people have another advantage over Japanese from the aspect of heat acclimatization. The temperature gradient between the core to the periphery for Thai was higher than that for Japanese in high temperature conditions. Accordingly, the heat transfer coefficient of Thai is higher than that of Japanese suggesting that the capacity of heat transfer from the core to the periphery in Thai is superior to that of Japanese in hot environments. Therefore, the high coefficient of heat transfer in Thai indicates an improved cutaneous blood flow due probably to an increased circulating blood volume, which is a favorable sign of heat acclimatization.

(4) Studies on the Human Adaptability Section of IBP in Japan

In 1964, the International Biological Program (IBP) was established in Paris with the aim of performing, under international cooperation and coordination of biologists, fundamental research on the biological basis of productivity and human welfare. As one of the sections of IBP, research on human adaptability (HA) was included. The Science Council of Japan decided to cooperate in IBP under the leadership of Dr. H. Tamiya (1903-1984), chairman of the Japanese Committee of IBP (JIBP), and H. Yoshimura was appointed convener of the HA section of JIBP (JHA). The activities of JIBP started in 1965 and continued until 1972 with an additional two years for synthesis (10 years in total).

JHA activity started after an international symposium on "Human Adaptability and its Methodology" in Kyoto (Yoshimura *et al.*, 1966) as a satellite symposium of the 23rd International Congress of the International Union of Physiological Sciences (IUPS) in Tokyo. Among the projects, the following were closely related to environmental physiology : 1) analysis of thermal tolerance and its methodology, 2) adaptability of circadian rhythm in human ecosystems, 3) acclimatization to high altitude in an expedition to the Andes, 4) comparative studies on human adaptability of Japanese, Caucasian Americans and Japanese Americans, 5) physiological adaptability of Japanese in the Antarctic, and 6) problems on the adaptability of the "ama" and other underwater workers. Each of the project studies has contributed to the development of environmental physiology in Japan and is still expanding its study field. Because of the limited concern of this review article, only the topic of "analysis of thermal tolerance and its methodology" will be introduced hereafter.

1) Analysis of Thermal Tolerance and Its Methodology

(a) Ogata and his colleagues (Ogata & Sasaki, 1975) devised a method for examining whole body tolerance to cold by exposing a resting subject for 1 hour to a certain standard cold environment. The increment of oxygen consumption (M) and decrement of mean skin temperature (T) of the subject with light clothing were measured. They found that M/T determined at 40-60 min after cold exposure at 10°C was a good measure of whole body cold tolerance, since this ratio gave a reliable and reproducible result. This method was shown to be superior to the 8-hour sleeping method recommended in the IBP/HA Handbook (Weiner & Lourie, 1969).

(b) Ohara (1972) devised a method to test heat tolerance by measuring the subject's ability to perspire. He found that an individual who had a low sweat rate and a low sweat concentration of chloride had the highest score in estimated heat adaptability.

(c) Field studies for surveying thermal tolerance in sojourners in subtropical (Okinawa) and subarctic (Hokkaido) areas were successfully conducted. In the former survey, focus was placed on the rise of body temperature and sweating of the residents under hot conditions (Hori et al., 1976), and in the latter study, lipid metabolism in relation to the adaptation to cold was extensively investigated (Itoh, 1974).

(d) Seasonal variation of BM (low in summer and high in winter) has been observed among people whose main crop is rice in Asian countries, including Japan, Korea, Thailand and India (Hori *et al.,* 1977 ; Ohnaka *et al.,* 1978). Interestingly, however, the seasonal changes in BM observed in the Japanese in earlier phases of the project (Nakamura *et al,* 1964 ; Nakamura *et al.,* 1969 ; Yoshimura *et al.,* 1966) gradually diminished in later observations (Yurugi *et al.,* 1972) when the food composition of the Japanese diet approached that of western countries, i.e., from low fat diet to high fat. These observations confirmed an intimate relationship between fat content in the diet and thyroid function, hence oxygen consumption, in humans (Yoshimura, 1960) and in experimental animals (Yurugi, 1972).

3. FUTURE IMPLICATIONS

Recent trends in thermal physiology seem to lay importance on the role of the central nervous system in thermoregulation. Although it is obvious that this basic research is important, additional emphasis should be given to the integrative role of various organ systems connected to practical applications for the overall benefit of humans. Analysis and integration should be like the two wheels of a cart. Recently, new environments, e.g., space and great depth in the sea are being exploited as working or living places of humans. Environmental physiology should be developed to meet the challenges of these new environments. A promising step toward meeting these challenges is now being carried out in several institutions in Japan.

REFERENCES

Harashima, S. (1953). Seasonal variation in serum K, Ca and pattern of percentage of various types of leucocytes. Nisshin Igaku,. **40** : 574-580 : 574-580.

Hori, S., H. Iizuka, and M. Nakamura. (1976). Studies on physiological responses of residents in Okinawa to a hot environment. Jpn. J. Physiol. **26** : 235-244.

Hori, S., M. Ohnaka, K. Shiraki, J. Tsujita, H. Yoshimura, M. Saito, and P. Migasena. (1977). Comparison of physical characteristics, body temperature and basal metabolism between Thai and Japanese in a neutral temperature zone. Jpn. J. Physiol. **27** : 525-538.

Itoh, S. (1974). Physiology of Cold-Adapted Man. Hokkaido Univ. School of Medicine, Sapporo.

Kim, S. (1965). Studies on basal metabolism, caloric expenditure and daily energy expenditure of Korean students in middle school, high school and college. J. Korean Modern Med. **3** : 291-294.

Kuno, Y. (1934). The physiology of human perspiration. Churchill, London.

Kuno, Y. (1956). Human Perspiration. C.C. Thomas, Springfield.

Malhotra, M.S., S.S. Ramasmamy, and S.N. Ray. (1960). Effect of environmental temperature on work and resting metabolism. J. Appl. Physiol. **15** : 769-770.

Nakamura, M., S. Usutani, R. Ishida, and Y. Ogino. (1964). On the adaptation of the basal metabolism to the climate. Hirosaki Med. J. **16** : 137-151.

Nakamura, M., S. Usutani, T. Horimae, and K. Sugawara. (1969). Local specificity of the seasonal variation in basal metabolic rate of Japanese. Tohoku J. Exp. Med. **92** : 297-299.

Nohara, H., M. Nakamura, K. Sugawara, M. Sugawara, K. Kuwano, M. Tsuchimoto, T. Kawazoe, K. Yoshida, and K. Morimoto. (1974). Cold vascular reaction, function of sweating and basal metabolism of the inhabitants in Okinawa. Jpn. J. Hyg. **29** : 150.

Ogata, K. (1949). Regulation of Body Temperature in a Cold Environment. Nanjoshoten, Tokyo.

Ogata, K. (1960). Physiological responses to cold. In Essential Problems in Climatic Physiology (eds. H. Yoshimura, K. Ogata, & S. Itoh), Nankodo, Kyoto. pp. 26-60.

Ogata, K. and T. Sasaki. (1975). Regional differences in the cold adaptability of the Japanese in physiological adaptability and nutritional status of Japanese, Chapt. 2, Part 1. In JIBP Synthesis. Vol. 3. (eds. H. Yoshimura, & S. Kobayashi), Tokyo Univ. Press, Tokyo. pp. 355-365.

Ogata, K. and T. Sasaki. (1975). Analysis of thermal tolerance and its methodology. In IBP Synthesis. Vol. 3. (eds. H. Yoshimura, & S. Kobayashi), Univ. of Tokyo Press, Tokyo. pp. 20-27.

Ohara, K. (1972). Salt concentration in sweat and heat adaptability. In Advances in Climatic Physiology (eds. S. Itoh, K. Ogata, & H. Yoshimura), Igaku Shoin, Tokyo. pp. 122-133.

Ohnaka, M., S, Hori, N. Saito, K. Shiraki, P. Migasena, and H. Yoshimura. (1978). The role of food habits in physiological adaptation of inhabitants of Southeast Asia to the habitat of tropical countries. In Progress in Human Nutrition. Vol. 2. (eds. R.A.O. S.Morgen), AVI Publ, Connecticut. pp. 219-235.

Shiraki, K., and M. K. Yousef (1987). Man in Stressful Environments : Thermal and Work Physiology, C. C. Thomas, Springfield.

Shoji, R. (1942). Cold tolerance to the cold. Review of Physiology in Japan. Nihon Seirigaku Hyoron. **2** : 59-68.

Takagi, K. (1960). Influence of skin pressure on temperature regulation. In Essential Problems in Climatic Physiology. (eds. H. Yoshimura, K. Ogata, & S. Itoh), Nankodo, Kyoto. pp. 212-249.

Valyasevi, A., S.B. Halstead, S. Pantuwatana, and C.

Tankayul. (1967). Studies of bladder stone disease in Thailand IV : Dietary habits, nutritional in take, and infant feeding practices among residents of a hypo-and hyperendemic area. Am. J. Nutr. **29** : 1340-1351.

Weiner, J.S. and J.A. Lourie. (1969). IBP Handbook, Blackwell Sci. Pub, Oxford.

Yanagi, S. (1939). Experimental studies on the influence of low temperature on the body, with special reference to cold death. Hokkaido Univ. Press, Sapporo.

Yoshimura, H., and T. Iida. (1950). Studies on the reactivity of skin vessels to extreme cold, Part 1. A point test on the resistance against frostbite. Jpn. J. Physiol. **1** : 147-159.

Yoshimura, H., and T. Iida. (1952). Studies on the reactivity of skin vessels to extreme cold, Part 2. Factors governing the individual difference of the reactivity, or the resistance against frostbite. Jpn. J. Physiol. **2** : 177-185.

Yoshimura, H. (1960). Acclimatization to heat and cold. In Essential Problems in Climatic Physiology (eds. H. Yoshimura, K. Ogata, & S. Itoh), Nankodo, Kyoto. pp.61-106.

Yoshimura, H. (1964). Organ system in adaptation : the skin. In : Adaptation to the Environment. In Handbook of Physiology, Section 4. Vol. Section 4. (eds. D.B. Dill, E.F. Adolf, & C.G. Wilber), Am. Physiol. Soc, Washington, DC pp. 109-131.

Yoshimura, M., K. Yukiyoshi, T. Yoshioka, H. and Takeda. (1966). Climatic adaptation of basal metabolism. Fed. Proc. **25** : 1169-1176.

Yoshimura, H. (1987). Past and future of environmental physiology : special reference to Japan. In Man in Stressful Environments : Thermal and Work Physiology (eds. K. Shiraki & M. K. Yousef), C. C. Thomas, Springfield. pp. 287-298.

Yurugi, R., T. Sasaki, and M. Yoshimura. (1972). Seasonal variation in basal metabolism in Japanese. In Recent Advance in Climatic Physiology (eds. S. Itoh, K. Ogata, & H. Yoshimura), Igaku Shoin, Tokyo. pp. 395-409.

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