Physical Characteristics and Decrement in Muscular Performance after Whole Body Cooling

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The dependence of cooling-induced decrement in muscular performance on several physical characteristics was studied. The characteristics were: the amount of subcutaneous fat, body weight, height and surface area, maximal aerobic capacity and maximal voluntary isometric contraction of the trunk flexors. Ten male subjects wearing shorts and jogging shoes were exposed to 27°C and 10°C for 60 min. The cooling resulted in a decrease of 6.8 ± 0.3 °C (mean \pm SE) in mean skin temperature. The temperatures of m. triceps and m. deltoideus were decreased by 2.8 ± 1.0 °C and 5.1 ± 0.4 °C, respectively. Rectal temperature was virtually unaffected. A significant negative correlation (r = -0.785) was found between the amount of subcutaneous fat and decrease in mean skin temperature after cooling. After the exposures to 27°C and 10°C, the subjects performed an overhead ball throwing test to measure muscular performance. The test was performed in a standing position using both arms. Five balls weighing from 0.27kg to 3.0kg were thrown. On the average, cooling decreased muscular performance 7.6%. The decrease correlated significantly only with the amount of subcutaneous fat (r = -0.710). The results indicate that from the measured physical characteristics, varying within normal range, only subcutaneous fat had significant effect on thermal responses. Accordingly, the decrease in muscular performance correlated only with the amount of subcutaneous fat.

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Decrement in muscular performance due to cooling is well verified (Bennett, 1984; Faulkner et al., 1990; Oksa et al., 1993). The decrease is related to the degree of cooling (Bergh, 1980). During short term dynamic exercise the performance has been reported to be reduced by $4-8\% \cdot ^{\circ}C^{-1}$ decrease in muscle temperature (Bergh and Ekblom, 1979; Davies and Young, 1983; Sargeant, 1987).

Individual differences in physical characteristics could modify the thermal responses to cooling. Firstly, subcutaneous fat acts as a thermal insulator against cool environment, slowering the rate of cooling as well as increase in oxygen consumption (Buskirk et al., 1963; Cannon and Keatinge, 1960; Keatinge, 1960). Secondly, with increasing body size the surface area-body mass-ratio decreases, consequently decreasing the relative area for heat loss. Along with the increase in body size the body heat content also increases. Due to these factors, increased body size slowers the rate of cooling (Buskirk and Kollias, 1969). Thirdly, the level of physical fitness affects thermal responses because a fit subject with high aerobic capacity is able to produce more heat than an unfit (Keatinge, 1961). However, the consequences of altered thermoregulatory responses on muscular performance have not been reported. Therefore, the purpose of this study was to evaluate whether physical characteristics affect Physical characteristics and performance after cooling.

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the cooling-induced decrement in muscular performance.

METHODS

Ten sedentary and healthy men (age 24 ± 4 , mean \pm SD) volunteered as test subjects (Table 1). They were medically examined before the study, the experimental protocol was explained and their written consent was obtained.

The amount of subcutaneous fat (F%) was estimated from skinfold thickness measurements. The measurements were done with a Harpenden caliper (British Indicators Ltd, UK), exerting a constant pressure on the skinfold. The four measuring sites were: *m. biceps, m. triceps, m. subscapularis* and *iliac crest* according to the method of Durnin and Rahaman (1967). At each site the measurement was repeated three times and the mean was taken to represent the skinfold thickness.

Body weight (BW) was measured with a balance, with the accuracy of 10g (Datex WM 204 B, Instrumentarium, Finland) and body height (BH) with the accuracy of 1cm. Body surface area (BSA) was calculated using BW and BH according to the equation of DuBois and DuBois (1916) : $BSA = 0.2025 \cdot BW^{0.42} \cdot BH^{0.725}$ Maximal aerobic capacity (\dot{VO}_2 max) was determined during a maximal oxygen consumption test using arm ergometer (Monark). This test started with a load of 25 W. The load was increased 12.5 W every third minute until exhaustion. The pedalling rate was 50 rounds \cdot min⁻¹. The oxygen consumption (Medikro 202 ergospirometer, Medikro, Finland) and heart rate (Polar sport-tester, Polar-Electro, Finland) were measured continuously. The highest value of oxygen consumption was taken to represent the maximal aerobic capacity.

Maximal voluntary isometric contraction (MVIC) of the trunk flexors was measured by a strain gauge dynamometer (Digitest, Finland), with the accuracy of 10 N. This test was done in a standing position. The subjects were fixed to the dynamometer from the chest, sacral region and knees. Three maximal flexions were performed with 1 min intervals and the highest value was taken to represent the MVIC of the trunk flexors.

To measure the effects of temperature on muscular performance the subjects were exposed to 10° C (cool) or 27° C (control) for 60 min in a climatic chamber. They were dressed in shorts and jogging shoes. During the exposures to different ambient temperatures, skin temperatures (7 sites) and rectal

Subj	F% (%•BW ⁻¹)	BW (kg)	BH (cm)	BSA (m²)	VO₂ max (m <i>l</i> • kg ⁻¹)	MVIC (N)
1	9.0	63.9	169	1.73	31.2	700
2	9.1	76.0	183	1.98	36.2	850
3	9.1	71.0	184	1.93	41.4	560
4	10.2	71.0	178	1.88	30.4	590
5	15.6	78.2	180	1.97	35.9	860
6	10.7	63.4	169	1.73	39.0	740
7	7.8	60.4	168	1.68	42.7	780
. 8	16.7	72.6	164	1.79	30.9	700
9	8.4	69.9	170	1.81	32.1	960
. 10	8.9	64.4	167	1.72	35.0	960
mean±SE range	11 ± 1.0 7.8-16.7	69 ± 1.8 60.4 - 78.2	173 ± 2 164-184	1.8 ± 0.04 1.68 - 1.97	35.4 ± 4.3 30.4 - 42.5	770 ± 43 560 - 960

Table 1 The physical characteristics of the test subjects. Abbreviations denote: amount of subcutaneous fat (F%), body weight (BW) and height (BH), body surface area (BSA), maximal aerobic capacity (VO₂ max) and maximal voluntary isometric contraction (MVIC) of the trunk flexors.

temperature (Tr, 10cm depth) (YSI 400-series, Yellow Springs Instrument, USA) were measured with one minute intervals and stored in a data logger (Squirrel 1200, Grant, UK). Mean skin temperature (T_{sk}) was calculated by weighting the 7 local skin temperatures by representative areas (Mitchell and Wyndham, 1969). Body temperature (T_b) was calculated by the equation : $T_b = T_{sk} \cdot 0.35 + T_r \cdot 0.65$. Body heat content (Q) was calculated by the equation : Q (kJ)=3.48 · T_b · BW (Minard 1970).

Resting muscle temperatures (T_m) of four subjects from *m. triceps brachii* and *m. deltoideus* were measured with a needle electrode (YSI 511, Yellow Springs Instrument, USA) from the depth of 20mm and 30mm in another occasion after similar exposures.

After the exposures the subjects performed an overhead throwing test with both arms, in which five balls, weighing 0.27, 0.58, 1.0, 2.0 and 3.0kg were thrown. The flight times of the balls were measured with the accuracy of 0.001s (Digitest 1500, Finland) by using ten infra-red beams and a contact mat functioning with on/off basis (Digitest, Finland). Time measurement was activated when the ball reached the infra-red beams and stopped when the ball hit the contact mat attached to the wall 2.5m behind the infra-red beams. This test was performed in a standing position. The subjects were holding the ball in front of them and after a signal they lifted the ball above their head and threw it with full effort. The velocity (V) of each ball was calculated : V = D/t

where D = distance (m) and

$$t = time (s)$$

Before the tests the subjects were allowed to get accustomed with the throwing exercise. The test was randomized by exposure and ball weight.

In statistical analysis of the data, Student's t-test, correlation analysis and multiple regression analysis were used. Significance was accepted at p < 0.05 level.

RESULTS

After the exposure to 10°C the calculated heat debt was $9kJ \cdot kg^{-1} \cdot A$ significant decrease in T_{sk} and T_m was observed, whereas T_r was virtually unaffected (Table 2).

 T_{sk} and the local temperature of the arm, measured at the end of the exposure to 10°C, correlated significantly with F% and BW (Table 3).

The decrement in ball velocities after cooling varied from $1.4 \text{m} \cdot \text{s}^{-1}$ (0.27kg ball) to $0.6 \text{m} \cdot \text{s}^{-1}$ (3.0kg ball), the average decrement of all balls being $0.93 \pm 0.16 \text{m} \cdot \text{s}^{-1}$ (mean ± SE). The average decrement in ball velocity corresponds to 7.6% decrement in muscular performance.

A significant, negative correlation was found between F% and decrease in muscular performance (Table 3). Other physical characteristics did not correlate significantly with the decrement in perfor-

Table 2 The effect of 60 min exposures to 27° and 10° on rectal (T_r), mean skin (T_{sk}) and muscle temperatures (T_{mt}=m, triceps brachii, T_{md}=m. deltoideus from the depth of 30mm and 20mm).

			30mm depth		20mm depth	
	Tr	Tsk	T _{mt}	T_{md}	T _{mt}	T_{md}
27°C	36.9 ± 0.1	31.8 ± 0.5	32.7 ± 0.7	34.0 ± 1.1	32.1 ± 0.8	33.4 ± 1.2
10°C	36.8 ± 0.2	25.0 ± 0.6	32.2 ± 1.1	30.8 ± 0.7	29.3 ± 0.9	28.3 ± 0.7
diff	0.1 ± 0.2	6.8 ± 0.5	0.5 ± 0.2	3.2 ± 0.8	2.8 ± 1.0	5.1 ± 0.4
	NS	***	NS	*	*	* *

The values are mean \pm SE, n=10, in muscle temperature n=4. *=p<0.05, ***=p<0.001 and NS=not significant.

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Table 3 Correlation coefficients between physical characteristics, selected thermal responses (at the end of exposure to 10°C) and average decrement in muscular performance.

	Rectal temperature	Mean skin temperature	Upper arm temperatureª	Decrement in performance
F%	-0.522	-0.785*	-0.850**	-0.710*
BW	0.261	0.445	0.802**	-0.474
BH	0.393	-0.192	-0.219	0.113
BSA	-0.129	0.204	0.623	-0.226
VO₂ max	-0.162	0.632	-0.510	0.560
MVIC	0.414	-0.490	0.097	0.073

* = p < 0.05, ** = p < 0.01

alocal skin temperature measured above the midpoint of m. triceps.

mance.

Multiple regression analysis gave similar results as correlation analysis. The most powerful factor to explain the average decrement in muscular performance was F% (R=46%, p<0.05).

DISCUSSION

Whole body cooling used in this study decreased the body heat content $9kJ \cdot kg^{-1}$, on the average. The decrement was due to cooling of the superficial layers of the body, since T_{sk} decreased 6.8°C whereas T_r was virtually unaffected. Though the cooling did not affect T_r it did however, decrease significantly the temperature of the working muscles (Table 2).

The only physical characteristics which significantly affected the degree of cooling was F% (Table 3). This was seen as higher skin and lower muscle temperature of the leaner subjects. A 6% decrease in the amount of subcutaneous fat decreased T_m by 2°C at 10°C. This observation is in agreement with earlier studies where increased amount of subcutaneous fat has been found to decrease the rate of cooling (Baker and Farrington Daniels, 1956) by acting as a thermal insulator (Brück, 1986).

With the whole body cooling used in this study, the thermal responses were not affected by differences in physical fitness (\dot{VO}_2 max, MVIC) nor in body size. On the other hand, the local skin temperature above the working muscle *m. triceps* was affected by body weight (Table 3), indicating that large body mass can slower the rate of cooling.

Because only F% affected thermal responses, it is assumable that it would also affect muscular performance. This was confirmed by a high correlation between F% and decrement in muscular performance. The decrement was more pronounced with leaner subjects having lower Tm. The dependence was surprisingly clear considering the narrow range of F% (variation between 7.6-16.4%). This observation further emphasizes that even small amount of subcutaneous fat has a significant role as a thermal insulator against cooling. However, when the decrement in muscular performance is analyzed by multiple regression analysis, F% alone can explain only 46% of the decrement. Therefore, even though the other factors of physical characteristics did not reach statistical significance in the present study in explaining the decrease in performance, their effect can not be disregarded.

The power output during short-term dynamic exercises has been reported to decrease after cooling approximately $4-8\% \cdot C^{-1}$ decrease in T_m (Bergh and Ekblom, 1979; Davies and Young, 1983; Sargeant, 1987). Considering the mean temperature of *m. triceps* and *m. deltoideus* (from the depth of 30mm) as an overall representative of muscle temperature, the difference in T_m between exposures to 27°C and 10°C is 1.8°C. Consequently, the coolinginduced decrement in muscular performance in this

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study was $4.0\% \cdot C^{-1}$ decrease in T_m , which corresponds well with the previously reported values. In conclusion, the thermal responses of normal, sedentary subjects after cooling were significantly affected only by the amount of subcutaneous fat. Accordingly, the amount of subcutaneous fat was the only physical characteristics which effect was seen in muscular performance.

REFERENCES

- Baker, P. T., and Farrington Daniels, J. R. 1956: Relationship between skinfold thickness and body cooling for two hours at 15°C. J. Appl. Physiol. 8: 409-416.
- Bennett, A. F. 1984: Thermal dependence of muscle function. Am. J. Physiol. 16: 217-229.
- Bergh, U., and Ekblom, B. 1979 : Influence of muscle temperature on maximal muscle strength and power output in human skeletal muscles. Acta Physiol. Scand. 107 : 33-37.
- Bergh, U. 1980: Human power at subnormal body temperatures. Acta Physiol. Scand. 478 (suppl): 1 -39.
- Brück, K. 1986 : Basic mechanisms in thermal longterm and short-term adaptation. J. Therm. Biol. 11 : 73-77.
- Buskirk, E. R., Thompson, R. H., Whedon D. G.1963 : Metabolic response to cold air in men and women in relation to total body fat content. J.Appl. Physiol. 18 : 603-612.
- Buskirk, E. R., and Kollias, J. 1969: Total body metabolism in the cold. Bull. New Jersey Acad. Sci. March: 17-25.
- Cannon, P., and Keatinge, R. W. 1960: The metabolic rate and heat loss of fat and thin men in heat balance in cold and warm water. J. Physiol. 154: 329-344.
- Davies, C. T. M., and Young, K. 1983: Effect of temperature on the contractile properties and

muscle power of triceps surae in humans. J. Appl. Physiol. 55: 191-195.

- DuBois, D., and DuBois, E. F. 1916 : Clinical calorimetry X : A formula to estimate the appropriate surface area if height and weight be known. Archiv. Intern. Med. 17 : 863-871.
- Durnin, J. V. G. A., and Rahaman, M. M. 1967 : The assessment of the amount of fat in the human body from measurements of skinfold thickness. Br. J. Nutr. 21 : 544-550.
- Faulkner, J. A., Zerba, E., Brooks, S. V. 1990: Muscle temperature of mammals: cooling impairs most functional properties. Am. J. Physiol. 28: 259-265.
- Keatinge, R. W. 1960: The effects of subcutaneous fat and of previous exposure to cold on the body temperature, peripheral blood flow and metabolic rate of men in cold water. J. Physiol. 153: 166-178.
- Keatinge, R. W. 1961: The effect of repeated daily exposure to cold and of improved physical fitness on the metabolic and vascular response to cold air. J. Physiol. 157: 209-220.
- Minard, D. 1970: Body heat content. In: Hardy, J.
 D., Gagge, A. P., Stolwijk. J. A. J. (eds) Physiological and behavioral temperature regulation.
 Thomas, Springfield, Ill., USA, pp 345-357.
- Mitchell, D., and Wyndham, C. H. 1969 : Comparison of weighting formulas for calculating mean skin temperature. J. Appl. Physiol. 26 : 616-622.
- Oksa, J., Rintamäki, H., Hassi, J., Rissanen. S. 1993 : Gross efficiency of muscular work during step exercise at −15°C and 21°C. Acta Physiol. Scand. 147 : 235-240.
- Sargeant, A. J. 1987 : Effect of muscle temperature on leg extension force and short-term power output in humans. Eur. J. Appl. Physiol. 56 : 693 -698.

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