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This report primarily focuses on the influence of body mass, morphology and gender on thermal and metabolic responses during both rest and exercise after cold-water exposure. A group of male and female subjects ($n=4$ each) were evaluated that had similar ($P>0.05$) percent body fat and total skinfold, but differed ($P<0.05$) in weight, lean body weight, limb divided by trunk skinfold, surface area (A_D) and surface area-to-mass ratio (A_D/wt^{-1}). During both rest and exercise, testing was conducted at three water temperatures (20,24 and 28°C) for 1-h. Rectal temperature (T_{re}), mean-weighted skin temperature ($\bar{T}_{sk}$) and meta-

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bolic rate (M) were monitored during both rest and exercise. In a second series of experiments, metabolic and thermoregulatory responses of male volunteers differing in body morphology and mass during rest and exercise in water at 26°C were evaluated for 1-h duration. The large-mass and small-mass groups (n=5 each) were found to differ ($P<0.05$) in total body weight, lean body weight, $A_D \cdot wt^{-1}$, arm and leg volumes, but were similar ($P>0.05$) in percent body fat and total skinfolds. Similar thermoregulatory and metabolic responses were evaluated in these experiments as described above with the addition of esophageal temperature (T_{es}) and tissue insulation (I). Comparison between genders at rest showed a significantly greater decline in T_{re} over the 1-h immersion period for women at 20 and 24°C. No other significant differences in thermoregulatory and metabolic responses were observed between genders during rest or exercise. When the large-mass and small-mass groups were contrasted during rest and exercise at 26°C after 60 min, only final T_{es} and final I were different between these groups at rest. No other significant differences between these groups were observed during exercise. In conclusion, when these findings were taken collectively, it would appear that water temperature, body mass, and the exercise type and intensity are more critical factors to be considered in preventing a decline in deep body temperature during cold-water immersion than body fat, surface area-to-mass ratio and gender. We believe, however, that this conclusion is more applicable to individuals at exercise rather than rest during cold-water immersion.

INFLUENCE OF BODY MASS, MORPHOLOGY AND GENDER ON THERMAL RESPONSES DURING IMMERSION IN COLD WATER

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INTRODUCTION

Subcutaneous adipose tissue is known to provide insulatory benefits to humans during immersion in cold water (1-3). Individuals with greater subcutaneous fat demonstrate smaller physiological and thermal adjustments during cold-water immersion and greater exercise tolerance when contrasted to more lean individuals (4-6). However, far less is known about the impact of morphological and dimensional differences between individuals, such as body mass and surface area-to-mass ratio ($A_D \cdot wt^{-1}$), on the thermoregulatory adjustments to cold-water exposure.

The thermal and metabolic responses between individuals who differ in body mass and morphology may be further altered by movement of the limbs as in exercise compared to rest. When compared to rest, water-immersion exercise in cold water has been shown to either increase (7,8) or decrease (2,9) the rate of decline in deep body temperature. Finally, comparative data for cold-water exposures during rest and exercise between genders who generally display morphological and dimensional differences are relatively meager.

The purpose of this presentation is to summarize the recent experimental observations from our laboratory and from government contracted collaborative research with our laboratory that directly addresses these topics. Therefore, this paper will primarily focus on the influence of body mass, morphology and gender on thermal and metabolic responses during both rest and exercise after cold-water exposure.

METHODS

Series 1. A series of experiments were conducted to describe the metabolic and thermoregulatory responses between genders during both rest and exercise (36 W) for one hour in air (25-28°C) and in water at 20, 24 and 28°C.

The physical characteristics of the subjects, test protocol and associated methodology have been described in detail previously (1, 2); nevertheless, a brief summary of pertinent information necessary for this presentation is provided. Ten Caucasian college-aged male volunteers were categorized as low ($< 12\%$, n=4), average (15-18%, n=4), and high ($> 22\%$, n=2) in percent body fat while eight female volunteers of similar age were classified as low ($< 22\%$, n=4) and average (24-27%, n=4). However, two sub-groups between genders (n=4 each) were evaluated that had similar ($P > 0.05$) percent body fat and total skinfolds, but differed ($P < 0.05$) in weight, lean body weight, limb divided by trunk skinfold, A_D, and $A_D \cdot wt^{-1}$.

All testing in air and water at each of the three water temperatures (T_w) during both rest and exercise was randomly assigned. During all tests in both air and water, the subjects wore nylon swim suits. Experiments in water were conducted with the subjects immersed to the level of the first thoracic vertebrae. During the resting experiments, the subjects sat quietly for one hour during each exposure while for the exercise experiments subjects pedalled an arm-leg ergometer at 30 rpm for a similar time period. All water experiments were performed in stirred water which was maintained within $\pm 0.5^oC$ of the target T_w.

Percent body fat was determined by hydrostatic weighing while mean skinfold thickness was evaluated from the average of 10 skinfold sites. Metabolic measurements were evaluated using standard techniques for open-circuit spirometry. Rectal temperature (T_{re}) and mean-weighted skin temperature ($\bar{T}_{sk}$) which was determined from three sites (forearm, chest and calf) were continuously monitored during both rest and exercise.

Series 2. Another series of experiments were completed to describe the metabolic and thermoregulatory responses of male volunteers differing in body morphology and mass during both rest and exercise in water at 26°C for one hour duration. The physical and morphological characteristics of these subjects (10), test protocol and associated methodology (10-12) have been presented in detail elsewhere; therefore, only a brief description will be reported. Ten male subjects were divided into large mass (LM) and small mass (SM) groups (n=5, each) in an attempt to maximize differences in body mass and $A_D \cdot wt^{-1}$, but match groups for both subcutaneous and total body fat. The two groups were found to differ ($P < 0.05$) in total body weight, lean body weight, $A_D \cdot wt^{-1}$, arm and leg volumes, but were similar ($P > 0.05$) in percent body fat and total skinfolds (10).

Prior to all experimentation, subjects sat quietly in a room with a $T_a \sim 22^{\circ}C$ while wearing nylon swim suits. Then, subjects either rested on a chair or performed leg exercise on a modified water ergometer at a moderate exercise intensity ($\dot{V}O_2 \sim 1.5\ \ell \cdot min^{-1}$) for one hour while immersed to the neck in stirred water at 26°C (± 0.5°C). These experiments were conducted in a systematically varied fashion.

Similar measurements and techniques as described above for Series 1 were also employed for these experiments. However, esophageal temperature (T_{es}) was also measured and tissue insulation (I) calculated. In comparison to Series 1, total skinfold thickness was evaluated from 11 skinfold sites while $\bar{T}_{sk}$ was determined from five sites (calf, thigh, chest, triceps and forearm).

Statistical analysis. For the series 1 experiments, independent or paired t tests, analysis of variance for repeated measures and Duncan's multiple range tests, and in some instances Pearson product-moment correlation coefficients (r) were employed (1,2). For the series 2 experiments, analysis of variance for repeated measures with the Tukey multiple range and interaction post hoc test, and Pearson product-moment correlations coefficients were utilized (10). In all instances, the 0.05 level of significance was chosen for these analyses.

RESULTS AND DISCUSSION

Table 1 presents selected observations from the series 1 experiments between genders with comparable levels of body fat (16.8%, men; 18.5%, women). During rest at all three T_w, the decline in T_{re} over the 1-h immersion period was greater for the women as compared to the men being statistically significant at 20 and 24°C. Although not statistically significant, the T_{re} to $\bar{T}_{sk}$ thermal gradient was always greater for the men while final $\bar{T}_{sk}$ was consistently higher for the women. While the women demonstrated a greater decline in T_{re}, their resting metabolic rate (M) was not seen to differ significantly from the men at any of these T_w after 1-h of immersion. During exercise at all three T_w, the differences between genders after the 1-h immersion period for ΔT_{re}, final T_{re}, final $\bar{T}_{sk}$, final T_{re}-$\bar{T}_{sk}$ and absolute M (W) were not statistically significant ($P > 0.05$). The M in relation to surface area was also not different between genders during exercise at all three T_w for these same experiments (2).

INSERT TABLE 1 ABOUT HERE

Table 2 displays selected findings from the series 2 experiments comparing men divided into two groups in order to maximize differences in body mass and $A_D \cdot wt^{-1}$ while minimizing differences in subcutaneous and total body fat between groups. During rest, the M, T_{re} and $\bar{T}_{sk}$ did not differ ($P > 0.05$) between groups after 60 min of exposure at 26°C. However, T_{es} was significantly lower ($P < 0.05$) for the LM group during the same resting experiments at 60 min, but the change in T_{es} from pre-immersion to final values did not differ (SM, -0.2°C; LM, -0.4°C) between groups (10). Tissue insulation (I) during rest was seen to be higher ($P < 0.05$) for the LM compared to SM group at 60 min. During exercise, M, T_{es}, T_{re}, $\bar{T}_{sk}$ and I did not differ significantly

$(P > 0.05)$ at 60 min between groups. In general, experimental findings from additional rest and exercise tests on these same subjects, but performed in 18 and 30°C water, provided support for the above observations during immersion in 26°C water (13).

INSERT TABLE 2 ABOUT HERE

During rest in cold water, metabolic rate might be expected to differ between genders and/or groups differing in body mass making the interpretation of findings difficult. Thus, a constant intensity of leg exercise was also employed in these experiments to help eliminate this inter-individual variability in metabolism (10). Further, exercise with the legs only has been recently shown to be more effective than rest in preventing the decline in core temperature over time in both cool (30°C) and cold (18-20°C) water (11). Figure 1 illustrates that 1 h of leg exercise resulted in higher internal temperature responses (either T_{es} or T_{re}) when compared to rest (11). In contrast, arm and combined arm-leg exercise were not as effective as strict leg exercise in preventing the drop of core temperature in cold water as shown in Figure 2 (12). Figure 3 indicates greater conductive and convective heat loss after 45 min of exercise in cold water while employing the arms as compared to strict leg exercise (12). Mean weighted heat flow was area weighted from five sites (back, forearm, triceps, calf and thigh) in these experiments. In our series 1 or series 2 experiments, rest (1,2,10), arm-leg exercise (1,2) and strict leg exercise (10) were evaluated.

INSERT FIGURES 1,2 AND 3 ABOUT HERE

During our rest experiments in cold water, the women with the same percent body fat as the men were found to have greater difficulty in maintaining T_{re} when compared to these men (1). It should be noted that these women had a smaller lean body mass and a relatively larger $A_D \cdot wt^{-1}$ than the men indicating the importance of a larger inactive muscle mass in providing added insulation for the men during resting exposures in cold water. However, these same authors suggest the possibility that the sensitivity of the thermogenic responses may be enhanced in men when compared to women during rest in cold water (1). The thermal response contrasts between the large-mass and small-mass groups of men during rest in cold water further support the concept of added insulatory potential being associated with a larger muscle mass but for a subject population of the same gender (10). Whereas these two groups were similar in terms of percent body fat but differed in total body mass, lean body mass and $A_D \cdot wt^{-1}$, the large mass group most likely defended deep body temperature by employing a greater volume of muscle tissue to provide insulation without an increase in muscle metabolism. In contrast, the small-mass group appeared to increase metabolism twofold between pre-immersion and final immersion values in order to defend deep body temperature in cold water (10).

During exercise in cold water, a different picture emerges as the active skeletal muscle mass becomes perfused with warm blood and looses its resistance for heat transfer from the body core to water. When a major portion of the muscle mass is perfused by warm blood during exercise, all metabolic and thermal responses are similar between either men and women (2) or large-mass and small-mass groups of men (10) despite significant differences in $A_D \cdot wt^{-1}$ and body mass between groups. However, further data from our laboratory indicate that the distribution of the active muscle mass during exercise is an important consideration (12). Arm exercise results in greater conductive and convective heat loss than strict leg exercise in cold water. This probably results from (a) less fat insulation on the arms, (b) perfusion of an equal cardiac output to a smaller muscle mass causing greater blood flow per unit limb volume, and/or (c) a shorter axial conductive pathway from core to surface in the arms than legs (14). Further experimentation is necessary to fully understand the impact of exercise type on thermal responses during cold-water immersion.

In conclusion, when these findings are taken collectively, it would appear that the water temperature, body mass, and the exercise type and intensity are more critical factors to be considered in preventing a decline in deep body temperature during cold-water immersion than body fat, surface area-to-mass ratio and gender. We believe, however, that this conclusion is more applicable to individuals at exercise rather than rest during cold-water immersion.

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TABLE 1. Metabolic and thermoregulatory responses between genders of similar percent body fat for rest and exercise during immersion (~1-h) in water at 20, 24 and 28°C.

	20°C			24°C			28°C		
	Male	Female	Diff	Male	Female	Diff	Male	Female	Diff
Rest									
ΔT_{re}(°C)	-1.1	-1.6	-0.5*	-0.5	-1.2	-0.7*	-0.5	-0.9	-0.4
Final T_{re}(°C)	36.1	35.7	-0.4	36.6	36.2	-0.4	36.5	36.6	0.1
Final $\bar{T}_{sk}$(°C)	21.4	22.3	0.9	24.7	25.2	0.5	28.3	28.8	0.5
Final T_{re}-$\bar{T}_{sk}$(°C)	14.7	13.6	-1.1	11.7	11.1	-0.6	8.2	7.8	-0.4
Final M (W)	212	205	-7	142	163	21	118	135	17
Exercise									
ΔT_{re}(°C)	-0.7	-0.5	0.2	-0.1	-0.1	0.0	0.2	0.2	0.0
Final T_{re}(°C)	36.6	37.2	0.6	37.4	37.4	0.0	37.2	37.7	0.5
Final $\bar{T}_{sk}$(°C)	21.3	21.2	0.1	24.8	24.9	0.1	28.3	28.8	0.5
Final T_{re}-$\bar{T}_{sk}$(°C)	15.4	16.1	0.7	12.6	12.5	0.1	8.9	9.0	0.1
Final M (W)	340	330	-10	291	357	66	305	343	38

* Statistically significant at the $P < 0.05$ level.

TABLE 2. Metabolic and thermoregulatory responses between large-mass and small-mass groups for rest and exercise during immersion after 60 min in water at 26°C.

	Rest			Exercise		
	Large	Small	Diff	Large	Small	Diff
Final M (W)	152	198	46	550	527	-23
Final T_{es}(°C)	36.3	36.7	0.4*	37.2	37.3	0.1
Final T_{re}(°C)	36.5	36.5	0.0	37.4	37.3	-0.1
Final $\bar{T}_{sk}$(°C)	26.2	26.4	0.2	26.2	26.3	0.1
Final I ($^{o}C \cdot m^{-2} \cdot W^{-1}$)	0.166	0.106	-0.06*	0.039	0.036	-0.003

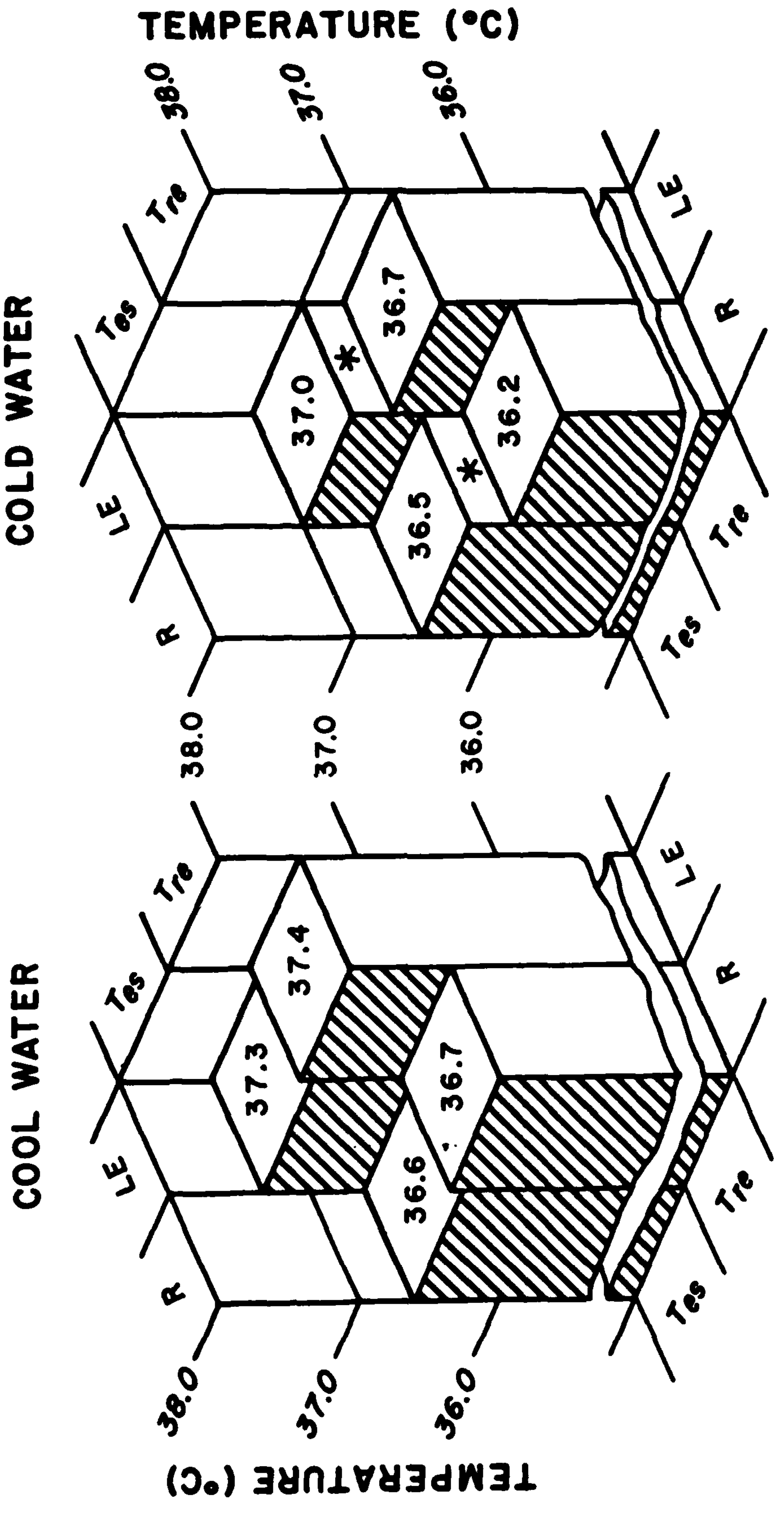
* Statistically significant at the $P < 0.05$ level.

FIGURE LEGENDS

Fig. 1. Comparison between rest and strict leg exercise of esophageal (T_{es}) and rectal (T_{re}) temperatures after 60 minutes in cool (30°C) and cold (18-20°C) water.

Fig. 2. Change (Δ) in rectal temperature responses after 45 minutes of exposure for arm, combined arm-leg, and leg exercise at water temperatures (T_W) of 20, 26 and 33°C.

Fig. 3. Final mean weighted heat flows after 45 minutes of exposure for arm, combined arm-leg, and leg exercise at water temperatures (T_W) of 20, 26 and 33°C.



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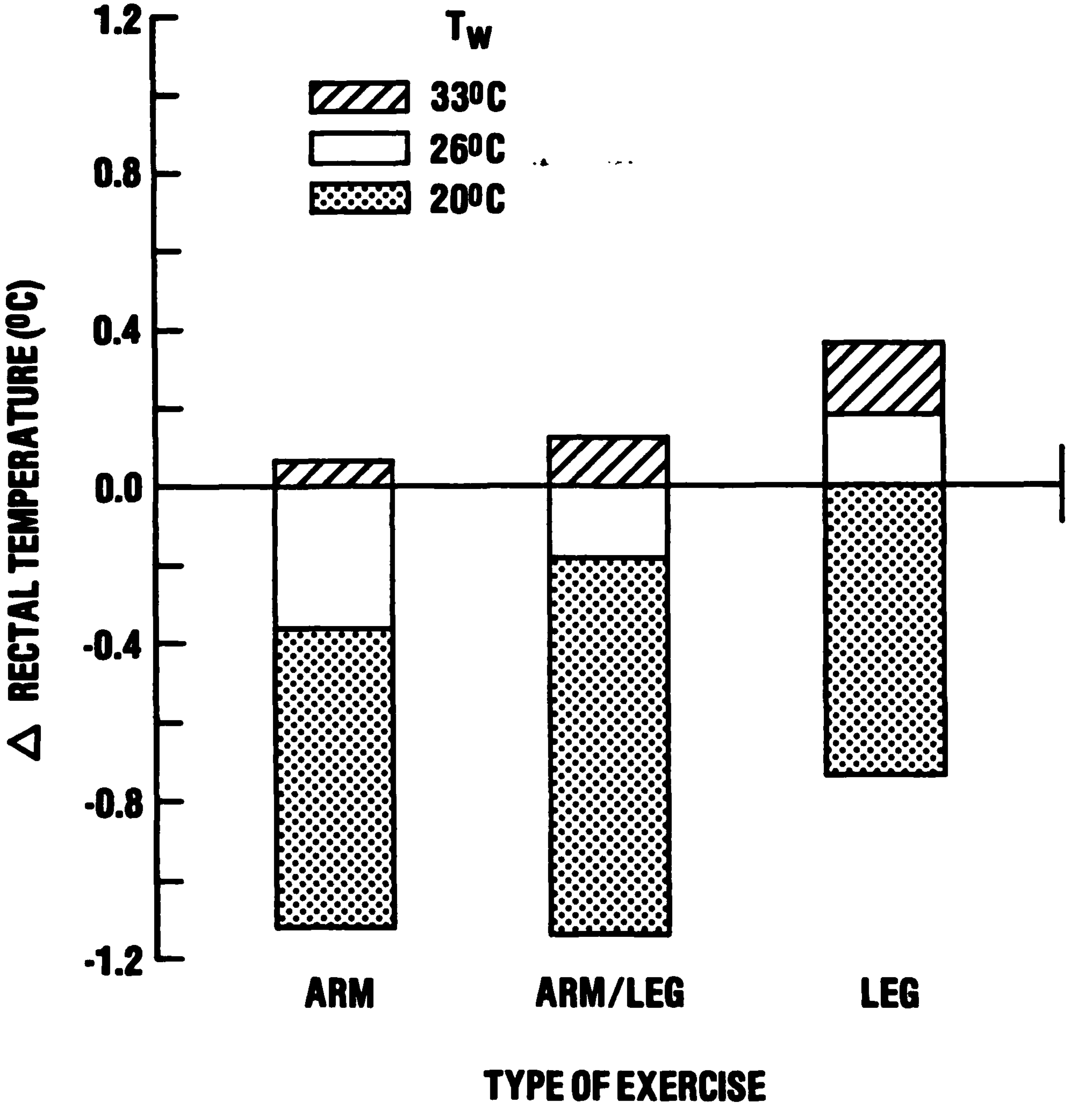
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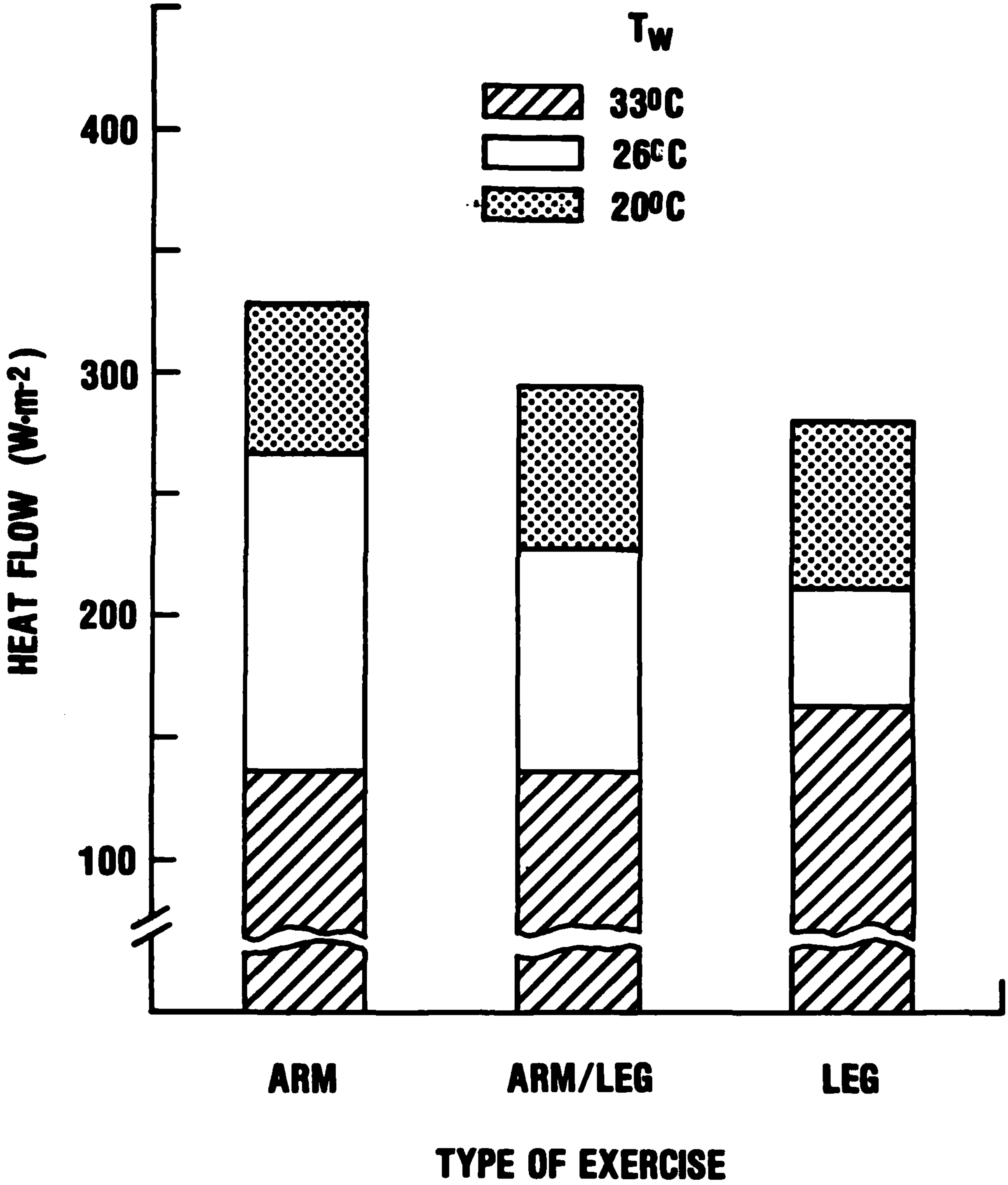Tw
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