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INFLUENCE OF MENSTRUAL CYCLE PHASE, ORALCONTRACEPTIVE USE AND SEX-RELATED DIFFERENCES ON HEAT TOLERANCE WHILE WEARING NBC PROTECTIVE CLOTHING

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EXECUTIVE SUMMARY

Canadian Forces personnel must be able to sustain operations in an environment contaminated with NBC agents. However, because of the thickness and low vapour permeability of the protective clothing ensemble, there is considerable heat strain associated with wearing full NBC protection in warm and hot environments. This report focuses on the problems of wearing the NBC clothing for women and how their responses compare with men. Due to oscillations in core temperature throughout the menstrual cycle, women who are non-users of oral contraceptives will show variations in heat tolerance when protective clothing is worn. Tolerance times will be the longest during the early follicular phase (days 2-5) of the cycle when starting core temperature is at its lowest value. Because of the increase in body temperature associated with ovulation, tolerance times will be reduced by about 10% during the luteal phase of the cycle. The use of oral contraceptives appears to eliminate these oscillations in heat tolerance. The proportion of body fat has a significant impact on the body's overall capacity to store heat. Those individuals, male or female, with a higher body fat content will have a reduced capacity to store heat and, therefore, a lower heat tolerance when protective clothing is worn. During light exercise, tolerance times for men while wearing the NBC clothing exceeded those for women by 25%. These sex-related differences in heat tolerance were eliminated when men and women were matched for body fatness. Commanders should be more concerned about the impact of body composition and fitness on heat tolerance while wearing the NBC clothing than the variations associated with the phases of the menstrual cycle.

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INTRODUCTION

During the past several years, the Human Protection and Perfromance Sector at the Defence and Civil Institute of Environmental Medicine has examined the heat strain associated with wearing nuclear, biological and chemical (NBC) protective clothing while performing exercise in warm and hot environments. This area of research was prompted by the Directorate of NBC Defence (DNBCD).

Canadian Forces personnel must be able to sustain operations in an environment contaminated with NBC agents. Clothing was designed, therefore, that effectively eliminated the interaction of the skin, eyes and respiratory tract with these toxic and potentially lethal agents. However, to acquire the desired level of protection, the clothing consisted of a thick, charcoal-impregnated semi-permeable overgarment together with impermeable rubber gloves, boots and respirator. As a consequence of the insulative qualities and low vapour permeability characteristics of the protective clothing, the effective control of body temperature is reduced. With normal operational or combat clothing, sweat production and evaporation increase in conjunction with the increase in heat production that occurs, for example, during physical work. Wearing the protective clothing, however, severly restricts heat loss through the evaporation of sweat. Therefore, core temperature increases more rapidly while performing continuous work and tolerance times are reduced compared with wearing combat clothing. We have documented the impairment associated with wearing the NBC clothing for males for different environmental conditions and have forwarded this information to DNBCD together with suggested strategies for the implementation of work and rest schedules (McLellan 1994). Further, a slide rule was developed for field use by the commander to assist in the estimation of tolerance times and work and rest schedules for the different levels of protective posture (low, medium and high), under various environmental temperatures and humidities, and levels of physical exertion.

Women comprise approximately 10% of the Canadian Forces and, in theory, they are expected to perform the same physical tasks as males which includes wearing the NBC clothing in a hot environment. Yet, to date, there have been no data compiled that have examined the responses of women during exercise in the heat while wearing the protective ensemble. Women may experience a greater impairment in work tolerance because of their oscillations in core temperature during the different phases of the menstrual cycle. For example, the elevation in core temperature of approximately 0.3°C during the luteal phase (after ovulation) of the cycle might be expected to shorten tolerance time during exercise. This is because the starting core temperature is critical in establishing performance capability in the NBC clothing which severly restricts evaporative heat loss (Aoyagi et al. 1995, Cheung and McLellan 1997). The influence of oral contraceptive use is prevalent among women of child-bearing age, and yet, the impact of these exogenous hormone supplements, which suppress ovulation, on work performance while wearing the protective clothing is unknown. Finally, women typically are less aerobically fit and have more adipose tissue than their male counterparts. Because adipose tissue has a lower specific heat than other tissues such as skeletal muscle, bone, and extra- and intracellular fluid, a given rate of heat production associated with exercise may cause the body tempertaure for women to increase faster than for men.

The purpose of this report, therefore, is two-fold. First, the findings from work unit 6fe12 funded by DNBCD entitled, "Heat tolerance in females while wearing NBC clothing", will be summarised. Second, a comparative analyses between men and women performing the same physical work under identical environmental conditions while wearing the NBC clothing will be presented and the implications of any sex-related differences in performance will be discussed.

Part 1: Heat Tolerance in Females While Wearing NBC Clothing.

For this study, both non-users (n = 9) and users (n = 9) of oral contraceptives were examined during three phases of the menstrual cycle (early follicular on days 2-5, late follicular on days 9-12 and mid-luteal on days 19-22) while wearing combat clothing and the full NBC ensemble. Subjects alternated 15-min periods of light work and rest under controlled environmental conditions of 40°C and 30% relative humidity. The trials continued for a maximum of 5 h, or until core temperature increased to 39.3°C (a safe but nontheless a substantial increase in body temperature from values close to 37°C), heart rate reached or exceeded 95% of the individual's maximum value, nausea or dizziness precluded further exercise, or the subject or a member of the scientific research team terminated the experiment.

Tolerance times for the combat (TOPP Low) and NBC (TOPP High) clothing configurations are presented in Figures 1 and 2, repsectively. Almost all of the women were able to complete the 5 h when combat clothing was worn and there was no difference in response between the users and non-users of oral contraceptives. In contrast, performing the intermittent exercise in TOPP High reduced tolerance times approximately 60% from 300 to 115 min. In addition, for the non-users, tolerance time was significantly increased 10-15% during the early follicular phase (130 min) of the menstrual cycle. This improvement in performance could be attributed to the 0.2°C lower starting core temperature. Tolerance times were not different throughout the menstrual cycle when oral contraceptives were used and these times were similar to those observed during the late follicular or mid-luteal phase for the non-users.

The findings from this study have shown that the menstrual cycle does not influence work performance when combat clothing is worn in a hot environment. In contrast, when the NBC ensemble is worn, tolerance is reduced about 60% and the phase of the menstrual cycle can exert an additional impact on performance for non-users of oral contraceptives. However, this impact is small compared with the overall impairment associated with the TOPP High configuration. Further, since the use of oral contraceptives negates any variations in performance throughout the menstrual cycle, commanders should not be concerned about the overall affects of the menstrual cycle on performance of women wearing NBC clothing in a hot environment.

Figure 1 **Combat Clothing**

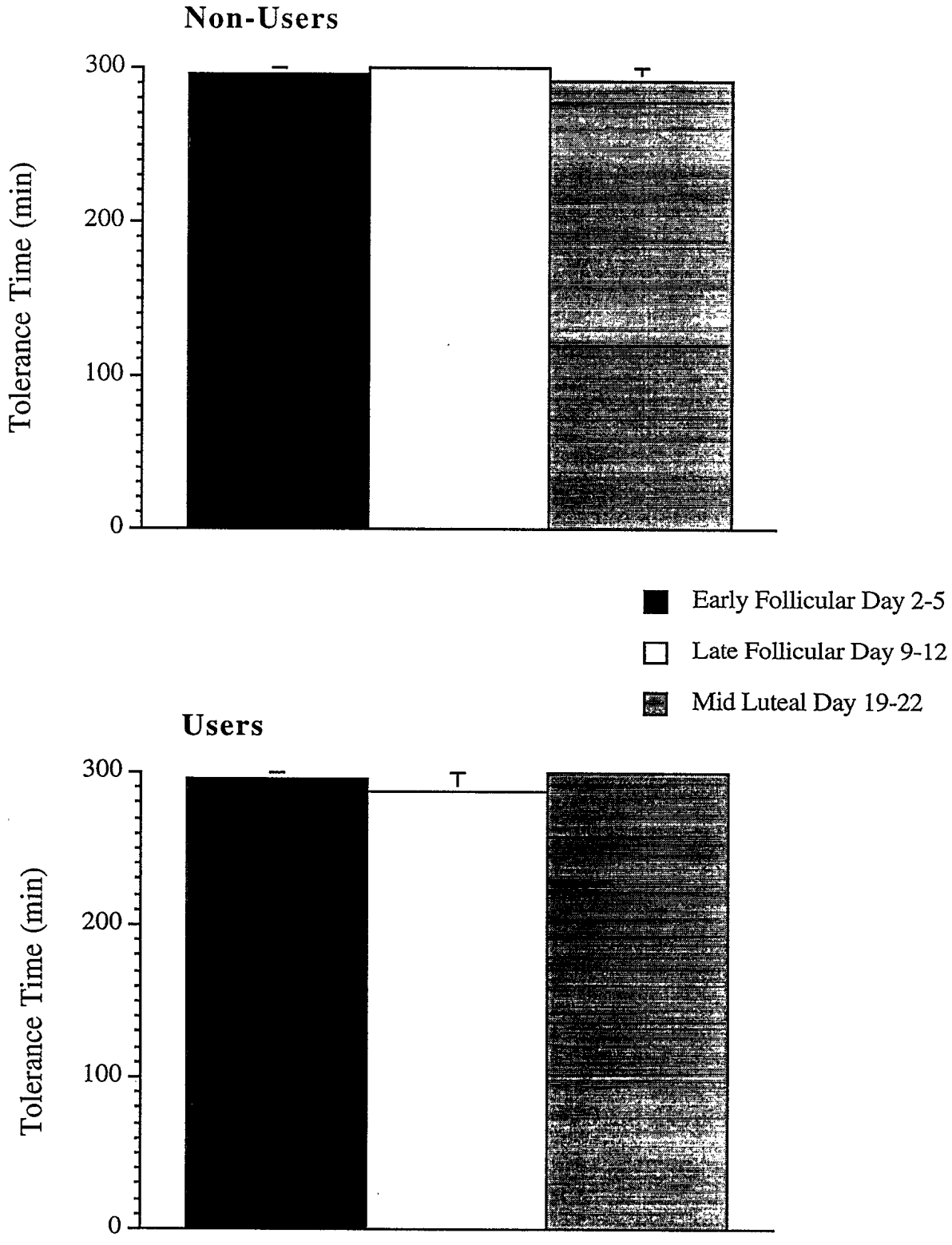
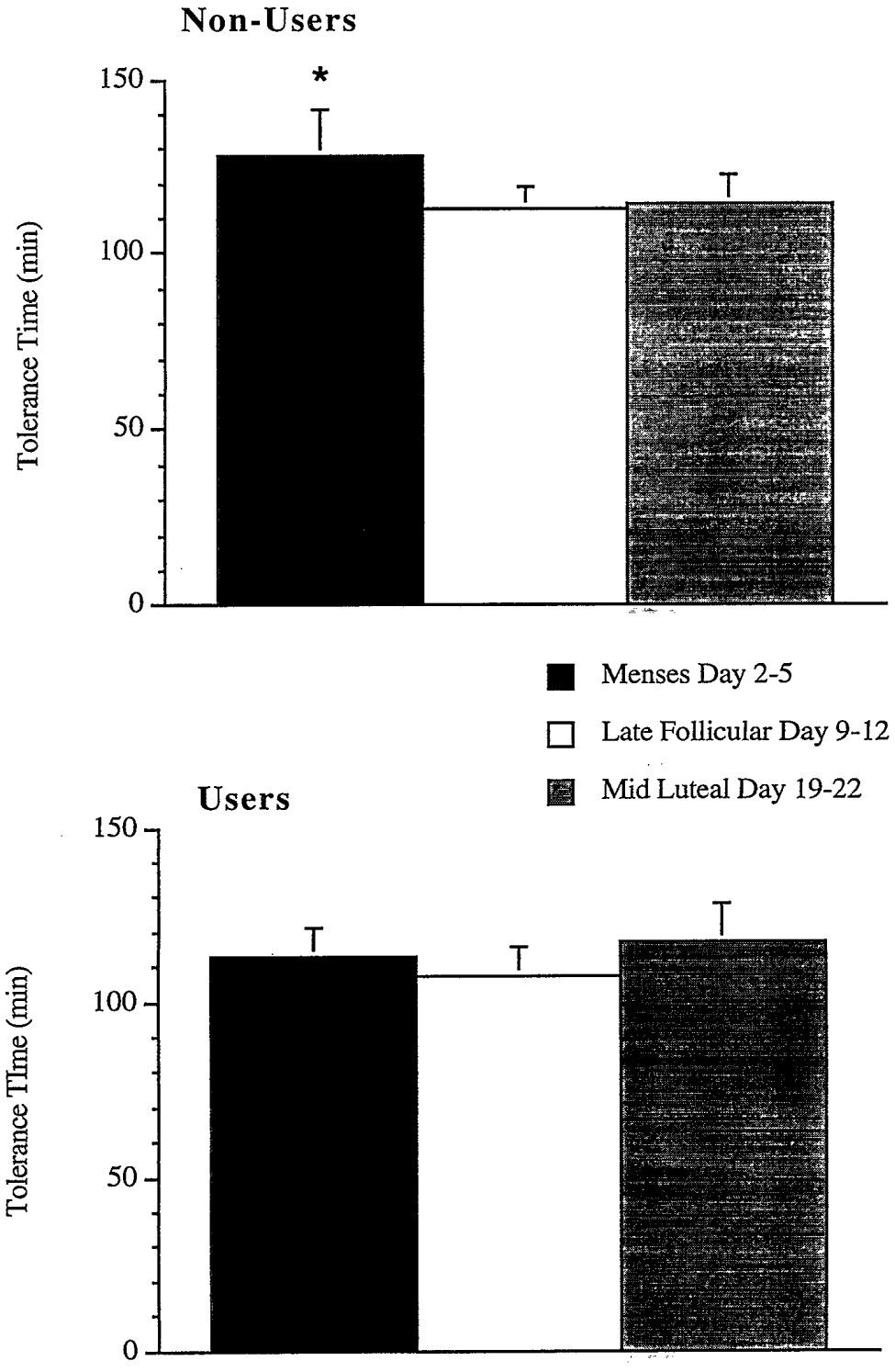


Figure 2 **NBC Clothing**



Part 2: Sex-Related Differences in Heat Tolerance While Wearing NBC Clothing.

Following the completion of the study described above, it was deemed of interest to compare the responses of men and women under identical clothing, exercise and environmental conditions. Data from 13 males who had exercised in the same hot environment while wearing the NBC ensemble (McLellan et al. 1994; McLellan 1996) were compared with the women's responses described above from the early follicular phase of the menstrual cycle. Data from this phase was used for comparison, since women appeared to be at a thermoregulatory advantage compared with the other times of their cycle. Descriptive data for the men and women involved in this comparative analyses are presented in Table 1. As expected, the men were of greater height and weight and, therefore, surface area, and they also had a lower surface area to mass ratio and body fatness, and a higher aerobic fitness ($\dot{V}O_2peak$). Also shown in Table 1 are various numbers of the men and women who could be matched for these different physical descriptors which are known to influence thermoregulation in a non-NBC clothing configuration. Supplementary analyses of the responses of these matched groups were then performed to determine the importance of these descriptors for explaining possible sex-related differences in heat tolerance in TOPP High.

Overall, heat tolerance was superior for the men. Rectal and skin temperatures, and heart rates were significantly lower during the intermittent work and rest schedule. As shown in Figure 3, tolerance times were approximately 30 min or 25% greater for the males. Estimates of heat storage per unit of mass ($kJ \cdot kg^{-1}$) were also greater for the men (Figure 4).

Matching of subjects for aerobic fitness alone or surface area to mass ratio failed to eliminate the differences in heat tolerance between the men and women. However, matching subjects for body fatness alone or in combination with aerobic fitness revealed that tolerance times (Figure 5) and heat storage (Figure 6) were not different between the sexes. Wearing NBC clothing severly restricts evaporative heat loss from the body. Thus, most of the heat produced for a given work intensity is stored in the body causing core temperature to increase. The magnitude of the increase in body temperature will depend on the specific heat of the body tissues. Since adipose tissue has a reduced capacity to store heat compared with other tissues of the body, an individual with a higher body fat content will show a larger increase in body temperature for a given amount of heat produced. Thus, women, who typically have a higher body fat content than men, will exhibit a faster increase in body temperature for a given work intensity and a decreased heat tolerance when the protective clothing is worn. Obviously, these sex-related differences in heat tolerance need not exist if the men and women have a similar body fat content, or they may exist among groups of men or women alone who differ with respect to body fatness.

Table 1 Age, mass, height, body surface area (BSA), BSA to mass ratio, body fatness (%BF), $\dot{V}O_2$peak and peak heart rate (HRpeak) for all subjects combined or matched for $\dot{V}O_2$peak, %BF, BSA to mass ratio or both $\dot{V}O_2$peak and %BF.

Subjects	Age (y)	Mass (kg)	Height (m)	BS A (m^2)	BSA/Mass ($m^2 \cdot kg^{-1} \cdot 10^{-2}$)	%BF	$\dot{V}O_2$peak ($mL \cdot kg^{-1} \cdot min^{-1}$)	HRpeak ($b \cdot min^{-1}$)
All Combined								
17 Females	23.2*	62.4*	1.65*	1.68*	2.71*	20.2*	43.2*	193.8
	(4.2)	(7.7)	(0.07)	(0.13)	(0.14)	(4.8)	(6.6)	(7.6)
13 Males	31.8	82.7	1.79	2.01	2.46	14.6	49.0	189.1
	(4.7)	(12.5)	(0.06)	(0.16)	(0.18)	(3.9)	(4.8)	(6.0)
$\dot{V}O_2$peak								
10 Females	22.3*	60.0*	1.63*	1.64*	2.75*	18.8*	46.9	192.0
	(3.3)	(8.4)	(0.07)	(0.14)	(0.16)	(3.1)	(6.2)	(7.8)
10 Males	30.8	85.4	1.81	2.05	2.43	14.7	48.4	189.8
	(4.1)	(12.8)	(0.03)	(0.15)	(0.18)	(4.2)	(4.9)	(6.2)
%BF								
8 Females	24.6*	60.7*	1.64*	1.65*	2.74*	17.3	45.7	192.0
	(5.4)	(8.4)	(0.08)	(0.14)	(0.15)	(2.3)	(7.9)	(8.4)
8 Males	32.3	86.9	1.79	2.06	2.38	17.2	47.3	190.0
	(4.2)	(10.5)	(0.08)	(0.16)	(0.12)	(2.2)	(3.3)	(5.8)
BSA/mass								
6 Females	24.3*	66.3*	1.68*	1.74*	2.64	19.7*	43.6	191.3
	(5.6)	(5.0)	(0.07)	(0.10)	(0.08)	(3.5)	(4.3)	(5.7)
6 Males	32.5	73.8	1.79	1.92	2.61	12.2	50.2	187.5
	(6.0)	(6.0)	(0.03)	(0.08)	(0.10)	(3.3)	(6.6)	(5.9)
$\dot{V}O_2$peak, %BF								
6 Females	22.8*	59.7*	1.61*	1.62*	2.74*	17.8	46.3	189.3
	(4.1)	(8.7)	(0.08)	(0.15)	(0.16)	(2.6)	(3.7)	(8.8)
6 Males	32.3	90.1	1.83	2.11	2.35	17.7	46.9	190.2
	(4.5)	(10.2)	(0.04)	(0.14)	(0.11)	(2.1)	(3.8)	(6.6)

Values are mean (S.D.). * significant difference between the sexes.

Figure 3

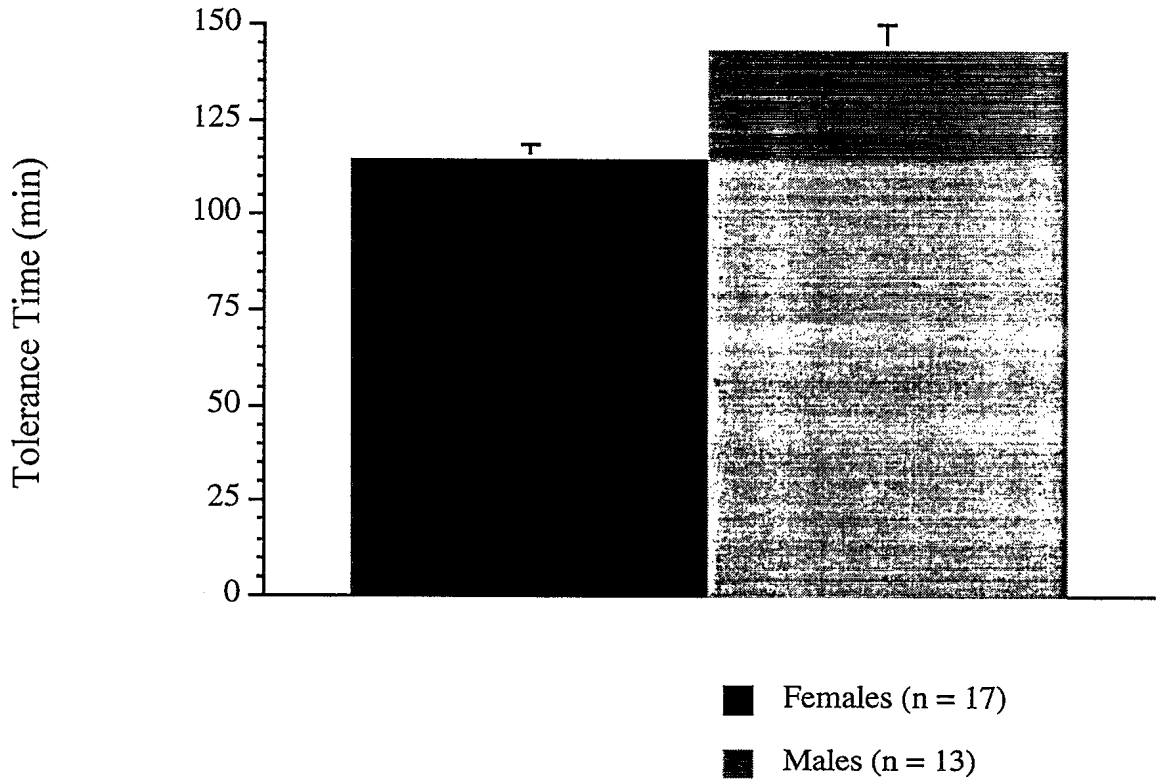


Figure 4

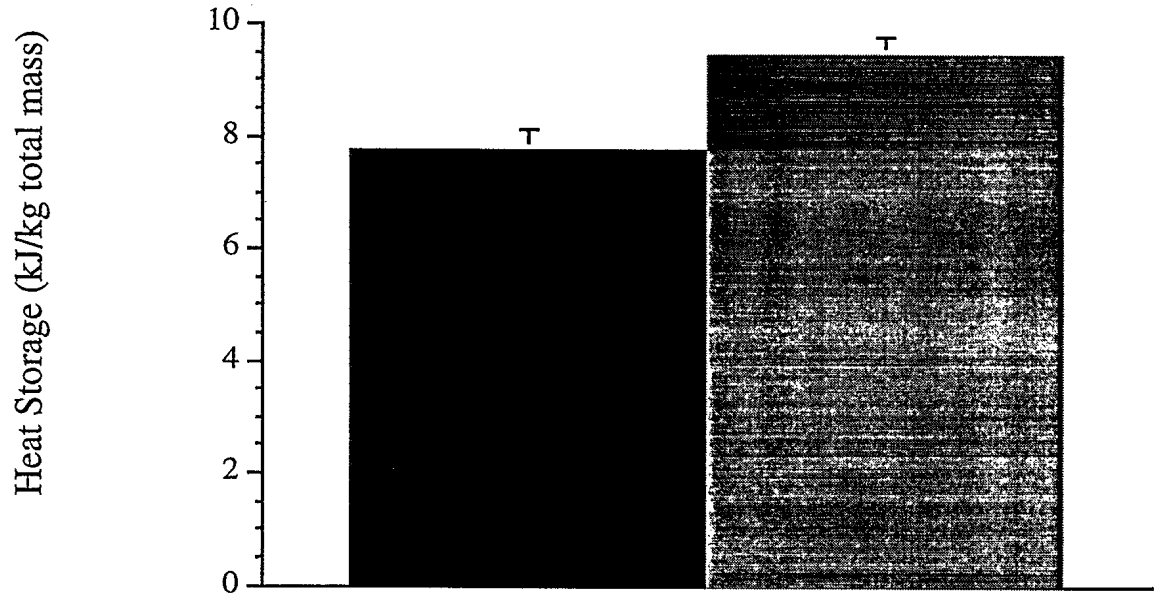


Figure 5 **Subjects Matched for Body Fatness**

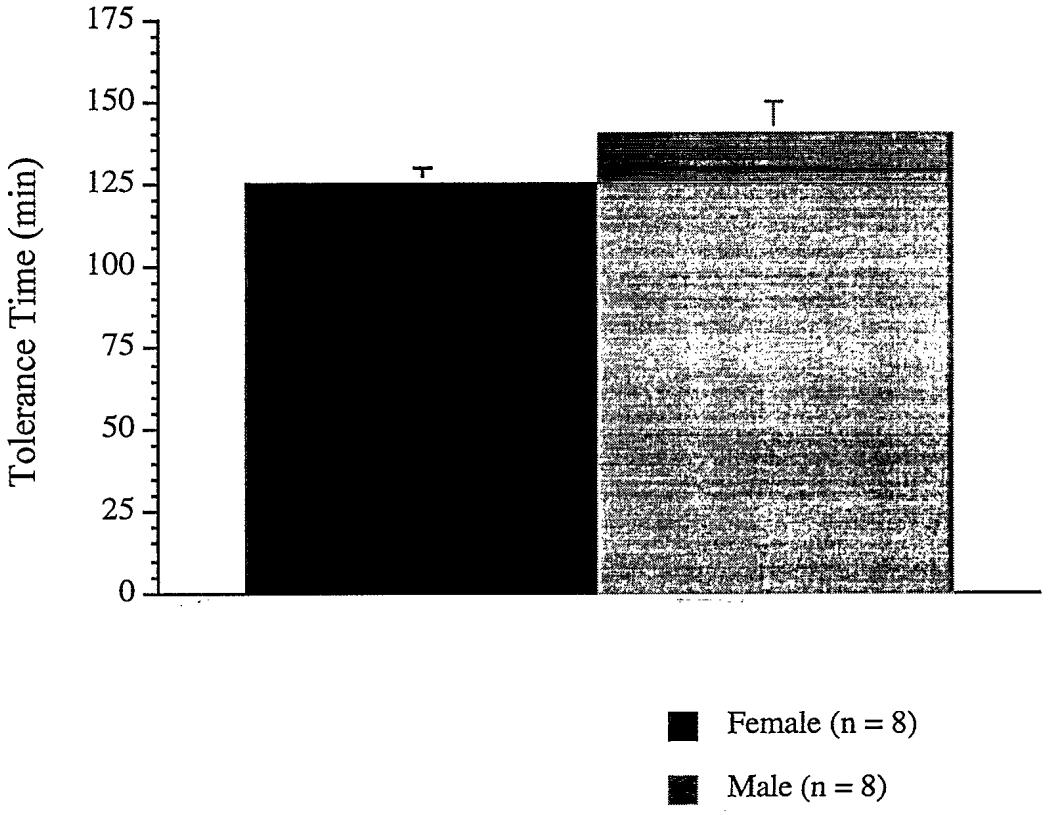
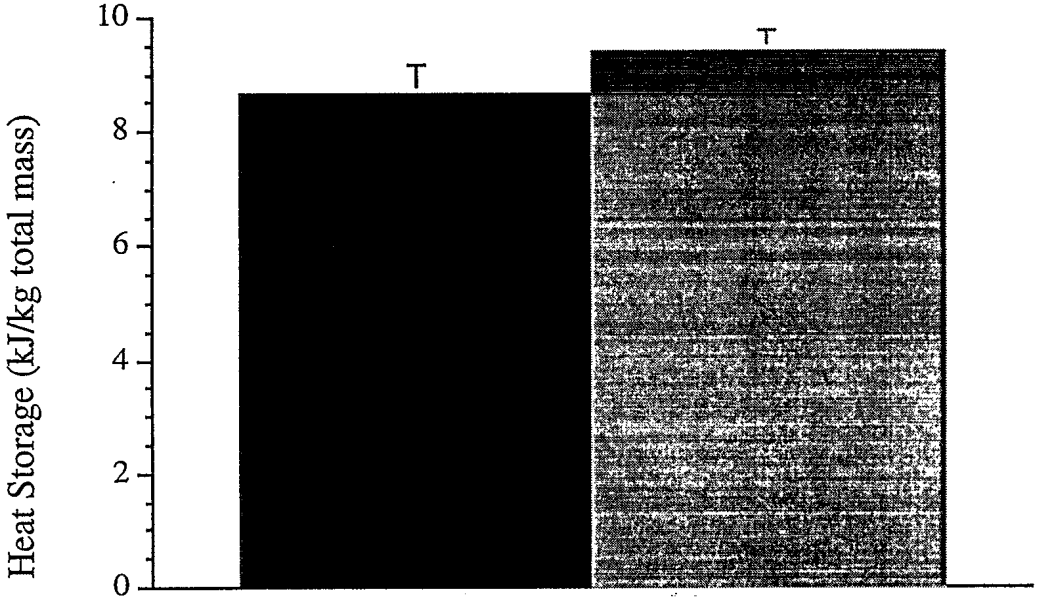


Figure 6



SUMMARY

Due to oscillations in core temperature throughout the menstrual cycle, women who are non-users of oral contraceptives will show variations in heat tolerance when protective clothing is worn. Tolerance times will be the longest during the early follicular phase (days 2-5) of the cycle when starting core temperature is at its lowest value. Because of the increase in body temperature associated with ovulation, tolerance times will be reduced by about 10% during the luteal phase of the cycle. The use of oral contraceptives appears to eliminate these oscillations in heat tolerance.

The proportion of body fat has a significant impact on the body's overall capacity to store heat. Those individuals, male or female, with a higher body fat content will have a reduced capacity to store heat and, therefore, a lower heat tolerance when protective clothing is worn. During light exercise, tolerance times for men while wearing the NBC clothing exceeded those for women by 25%. These sex-related differences in heat tolerance were eliminated when men and women were matched for body fatness.

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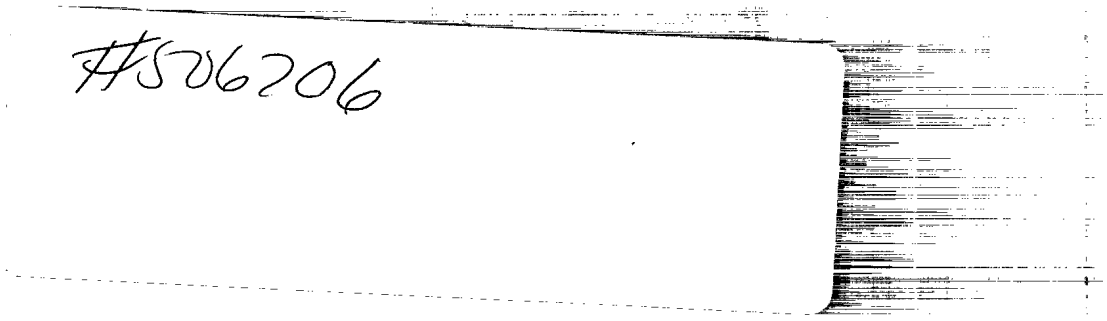
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