Decay of Acclimation and Time for Re-acclimation
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Abstract

Work in a warm or hot environment coupled with high metabolic loads and/or work in protective clothing can bring about considerable heat strain (e.g. increased heart rate and core body temperature). Acclimation by increasing exposure to work in a hot environment is one potent control used to reduce heat stress and decrease signs of heat strain. Documented physiological responses of acclimation include improved circulatory efficiency and enhanced sweating. Once workers are acclimated, physiological adaptations will persist as long as workers remain in the hot environment. Workers may be absent from the hot environment due to training, vacation, illness or normal shift change, and some adaptations may be lost requiring some degree of re-acclimation. OSHA recommends 5 days of re-acclimation for an absence from the heat of two weeks or more. These guidelines seem arbitrary as the decay of acclimation has not been fully explored. Also, re-acclimation has not been thoroughly evaluated. It seems logical that time for re-acclimation will depend on the degree of decay, and the time of complete decay of acclimation has not been established .

The basic philosophy of the experimental design was to determine the rate of decay of physiological adaptations of acclimation and the time to re-establish acclimation after complete loss of physiological adaptations. The first goal was to establish acclimation and then to determine the loss pattern of acclimation in 7-day increments over a period of approximately 6 weeks. Using a 3-day plateau in core body temperature as indication of full acclimation, acclimation was complete in approximately 8 days, suggesting that one can become acclimated in approximately 6 days, days 7 and 8 being used to confirm acclimation. To estimate the complete decay of acclimation, first the time for acclimation was considered. Based on the loss of physiological adaptation, it was estimated that on average, physiological adaptations for acclimation are completely lost in 42.5 days, or approximately 6 weeks.

The second goal of the study was to identify the time for re-acclimation based on the previous data collected. Based on this pattern, the loss pattern for 1/3 and 2/3 total loss of acclimation (2 weeks and 4 weeks, respectively) was determined. In our group of participants, there was no statistical difference in the time for re-acclimation with an average time for re-acclimation of 4.5 days.

Adequate acclimation can have a positive effect on heat tolerance by inducing physiological changes which help to reduce body temperature for a given work rate. Time away from the heat may result in loss of acclimation; increasing the risk of heat illness, injury and death. Our data suggest that complete loss of acclimation occurs with 6 weeks away from the heat. Further, our data suggest that re-acclimation may not be dependent on time away from the heat.

Significant Findings

Acclimation can have a positive impact on heat tolerance by increasing sweat rate, increasing plasma volume, and decreasing heart rate and T_{re} which helps to reduce body temperature and fatigue at a given work rate. Time away from the hot environment can result in loss of the physiological adaptations of acclimation; increasing the risk of heat illness, injury and even death.

Decay of Acclimation

The results of this project suggest that physiological adaptations of acclimation occur in approximately 6 days with moderate exercise in hot, dry conditions. As long as workers are in the heat, physiological adaptations of acclimation persist. Total loss of acclimation occurs with a 6-week absence from the heat.

Time forRe-acclimation

Based on a complete loss of physiological adaptations of acclimation of six weeks, 1/3 complete loss of acclimation (2 weeks) resulted in a time for complete re-acclimation of 4 days. Two-thirds complete loss of acclimation (4 weeks) resulted in one additional day for complete re-acclimation. The average time for re-acclimation was approximately 4.5 days. A period away from the heat of 1/3 and 2/3 complete loss of acclimation resulted in statistically equivalent times for re-acclimation. However, this data should be interpreted with caution as this project took place in central Florida. Although participants were requested to refrain from physical activity in the heat, it seems reasonable to assume that participants may have retained some acclimation from normal daily activity.

Translation of Findings

Once workers are acclimated to work in the heat, physiological adaptations will persist as long as workers remain in the heat. However, workers may be absent from the hot environment due to injury or illness, plant shut-down, training, or vacation, and physiological adaptations of acclimation may be lost requiring some degree of re-acclimation. The major contribution of this research was the establishment of decay pattern of heat acclimation and time to become re-acclimated after a period of time away from the heat.

Decay of Acclimation

Based on our results, workers do not lose all physiological adaptations of acclimation in two weeks as previously thought. Workers may retain some degree of acclimation up to 6 weeks, especially if the decay period is spent in a warm climate.

Time for Re-acclimation

This report suggests that re-acclimation after complete decay of acclimation occurs in 4-5 days and may not be dependent on the time away from the heat. However, these results should be interpreted with caution. Our subjects may have maintained some degree of acclimation in normal daily activities.

Background

Acclimation has a major influence on reducing the level of heat stress. The process of acclimation involves exposing workers to work in a hot environment for at least two hours over sequential days. NIOSH (12) suggests that for workers with previous work experience in the heat, the acclimation program should begin with 50% exposure on day one, 60% on day two, 80% on day three and 100% on day 4 in recognition of the increased work capacity that acclimation bestows. NIOSH (12) further recommends that the acclimation program for new workers begin with 20% exposure on day one with a 20% increase in exposure each day. These practical recommendations come from an understanding of the acclimation process described here.

Physiological Basis of Acclimation

The physiological adaptations of acclimation occur with environmental conditions sufficient to raise core body temperature and heart rate and can be achieved with two hours of heat exposure per day (23). Equivalent acclimation can be accomplished with exposure to a hot environment with low relative humidity (hot-dry) and with exposure to a warm environment with high relative humidity (warm-wet). Several researchers, however, have found greater physiological adaptations of acclimation with exposure to hot-dry heat (8, 21). Acclimation to dry heat was associated with a greater decrease in heart rate and core temperature due to a greater efficiency of sweating. High humidity environments prevent evaporation and thus are not effective for heat dissipation and result in higher physiological strain.

The major cardiovascular adjustments of acclimation are an increase in plasma volume and stroke volume and a reduction in exercise heart rate (4). Due to increased resting levels of ADH and aldosterone, fluid losses are minimized and plasma volume is increased (11,13). This physiological adaptation gives way to subsequent cardiovascular adjustments of increased stroke volume and decreased heart rate (3,13).

Physiological adjustments also occur in sweating and skin blood flow. Acclimation-induced changes in plasma volume facilitate skin blood flow with a smaller cardiovascular strain (2,6,7,8,17,18,21). There is an increased sweat response for a given core temperature as well as a decreased threshold of core and skin temperature for the onset of sweating (3,8,14,18). As such, one will begin to sweat at a lower thermal load and will sweat more for a given thermal load after acclimation. There is also a greater capacity for sweating; possibly coupled with an ability to sustain sweating for a longer period of time and an enhanced re-absorption of sodium by the sweat glands; making the sweat more dilute (11).

It has been generally accepted that cardiovascular adaptations in heart rate and plasma volume occur in the first few days of acclimation, and physiological adjustments in core temperature and sweating occur after approximately 6 days of acclimation (3). A review of a number of studies evaluating the acclimation process suggests that an average acclimation period of approximately ten days will reduce core temperature by approximately 0.70° C and that core temperature reached a plateau in approximately 7 days (6,8,10,14,17). The same acclimation period induced a 30 bpm reduction in heart rate, with complete adaptation evidenced by a plateau in heart rate in approximately six to seven days (8,10,17,18). In conclusion, acclimation serves to decrease heat storage and cardiovascular strain for a given thermal load; resulting in increased physical work capacity. The minimum documented time for acclimation is five days with some investigators using ten days to establish full acclimation (6,12,15,16,22). With these adjustments, there is a reduced risk of heat illness.

Complete acclimation is evidenced by a plateau in the physiological adaptations of acclimation such as decreased heart rate and core temperature and increased sweat rate, representing a new steady state for these variables (22). Heart rate is an early indicator of heat strain because the cardiovascular response increases before significant increases in heat storage and body temperature (22). However, heart rate is affected by a number of variables that may not be reflective of thermal load (11). The increase in core temperature appears to be the best predictor of excessive heat stress. As such, a plateau in core temperature reduction has been suggested as the major criteria used for complete acclimation (20,24).

Decay of Acclimation and Time for Re-acclimation

Once acclimation has been achieved, absence away from the hot environment will result in a loss of the favorable physiological adjustments. The physiological adaptations of acclimation are well-documented, however there is little known about the loss of acclimation. Assuming complete loss of acclimation in 2 weeks, OSHA (16) recommends a 5-day period of acclimatization for workers returning from an absence of two weeks or more. A limited number of research studies have evaluated the decay of acclimation when individuals stop working in a hot environment (2,9,17,18,22,24). In a review of the early studies, Givoni and Goldman (7) suggested that the decay rate is approximately 1 day for each two days away from work in the heat which led to the OSHA recommendations of two weeks of acclimation (16). However, the results of the early studies were based on incomplete acclimation, limited decay periods or brief re-acclimation periods (2,9,25). In addition, several studies used fit participants for their sample (2,25). The benefits of physical training and acclimation confer similar physiological adaptations such as increased sweat sensitivity and sweat capacity, increased plasma volume, increased stroke volume and decreased heart rate and core temperature for a given workload, and decreased core temperature and skin temperature for a given thermal load (5). The rate at which acclimation occurs is directly related to cardiovascular fitness. Pandolf et al. (17) reported a shorter acclimation period for those with the highest aerobic capacity (max VO_2).

There are several better-controlled studies that have examined the question of loss of heat acclimation and time for re-acclimation. Pandolf et al. (17) found no significant decay of acclimation after three, six, 12 and 18 days in 24 soldiers. However, Williams et al. (24) examined the decay of acclimation in South African mine laborers for periods of one, two and three weeks and determined that the physiological adaptations in heart rate and sweat rate vanished after 3 weeks of decay and adaptations of core temperature incurred a 50% loss at 3 weeks. In a study on decay and re-acclimation in six women, Stephens and Hoag (22) observed a loss of 45% in heart rate adaptations after four days absence from the heat and a 68% loss after eight days away from the heat. The adaptation in core temperature showed a slower rate of decay with a loss of 66% after 4 days of decay and a loss of 77% after 8 days of decay. This is a greater rate of decay than that suggested by Pandolf et al. (17) and Williams et al.(24). The reason for the discrepancy in the studies is likely due to sample size and fitness of the participants. The study by Stephens and Hoag (22) included a total of six women split into two groups according to type of acclimation, hot-dry or warm-wet. There were 24 and 60 men in the studies by Pandolf et al. (17) and Williams et al. (24), respectively. Generally, men are more physically fit than women. Because of their vocation, the men in the studies were accustomed to performing physical activity conferring a greater degree of physical fitness than the small group of women reported by Stephens and Hoag (22). As previously mentioned, physical fitness and heat acclimation confer similar physiological adaptations.

Specific Aims

Work in a warm or hot environment can bring about signs of heat stress such as increased heart rate and core body temperature. High metabolic loads and work in protective clothing can exacerbate the stress. If the worker is not acclimated to the heat, the likelihood of worker safety and productivity impairment is greater. A sound acclimation program can reduce the level of heat strain incurred by workers, and reduce the risk of heat illness and lost work capacity.

Documented physiological responses of acclimation include improved circulatory efficiency and enhanced thermoregulation. Circulatory changes include improved cardiac output accomplished by an increase in plasma volume, increased stroke volume, and decreased heart rate for a given workload (2,6,8,17,18,21). In addition, there is a deceased core temperature for a given workload (6,8,14,17,18), and a lower core temperature and skin temperature for the onset of sweating as well as increased sweat rate (3,8,14,18). Increase in core temperature is the best predictor of limiting conditions for heat stress. As such, a plateau in core temperature has been suggested as the major criteria to designate complete acclimation (20,24).

Once workers are acclimated to work in the heat, physiological adaptations will persist as long as workers remain in the heat. However, workers may be absent from the hot environment due to injury or illness, plant shut-down, training, or vacation, and physiological adaptations of acclimation may be lost requiring some degree of re-acclimation. However, the rate of decay of acclimation is not well known, and as such, the time required for re-acclimation in unknown.

The basic premise of this project was to first map the decay of acclimation and systematically determine the time to re-establish acclimation. The Year 1 goal was to determine the decay of acclimation. The Year 2 goal was to identify re-acclimation times for two points on the decay curve from Year 1. Based on the Year 1 information, the points representing 1/3 and 2/3 of total decay of acclimation were determined and the time for full re-acclimation were determined for each.

Methods

General Methods

Participants

The study protocol was approved by the USF IRB. Sixteen participants were recruited for each phase of the study from the Tampa Bay area via word of mouth and advertisements in local newspapers.

Prior to any physiological testing, participants providde written informed consent. Before beginning any testing, participants were examined by a licensed physician and approved for participation. Participants judged by the physician as inappropriate for the study were excluded. Exclusion criteria included drug or alcohol abuse, history of cardiovascular or pulmonary disease or regular use of any of the following medications: alpha and beta blockers, anticholinergics, antidepressants, antihistamines, calcium channel blockers, cocaine, diuretics, dopaminrgics, neuroleptics, and sympathomimetics. Women were excluded if they were pregnant at the beginning of the sturdy or if they became pregnant during the course of the study. All women were given a home pregnancy test and asked to self report the results.

Prior to beginning the acclimation process, all participants underwent a test of maximal aerobic capacity (max VO_2) on a treadmill using the Bruce protocol (1). During the test, heart rate was monitored continuously and recorded every minute. Expired gases were collected continuously using a Vacumed Vista Mini-CPX Expired gases were analyzed for a plateau in oxygen consumption between two consecutive stages. Leveling off of oxygen consumption with increasing intensity provides assurance that one has reached their maximal capacity for aerobic metabolism. However, all participants were not able to achieve this goal, and as such, "peak VO_2" was used to indicate aerobic capacity.

Equipment

Experiments were conducted in a Model 7010 climatic chamber designed by Forma Scientific. Work was performed on a treadmill and the speed and grade were used to control the metabolic rate. Heart rate was monitored using a Polar heart rate monitor. Rectal temperature (T_{re}) was measured using a flexible thermistor inserted 10 cm beyond the anal sphincter muscle. Sweat rate was established from the difference in semi-nude weight pre- and post-trial adjusted for fluid intake.

Assessment of oxygen consumption was used to establish metabolic rate using a Vacumed Vista Mini-CPX Metabolic Measurement System. Expired air was collected for 5 minutes at regular intervals during the trials.

Protocol

Each participant underwent an acclimation period up to 10 consecutive days (excluding weekends) by walking on a treadmill daily in a climatic chamber. Environmental conditions of the chamber were set at 50° C and 20% rh. The treadmill speed and grade were set to elicit a moderate metabolic rate of approximately 40% max VO_2,a moderate rate of work. Treadmill speed and grade for the workload were established and confirmed during the first two days of acclimation.

During each trial, air samples were taken at 30, 60, and 90 minutes into a trial. In addition, heart rate and T_{re} were monitored continuously throughout the trial and recorded every five minutes. Each testing session lasted approximately 2 hours unless one of the termination criteria was met.

Termination Criteria

- Core temperature greater than or equal to 39° C
- Sustained heart rate greater than 90% of the age-predicted maximum heart rate
- Participant wishes to stop

A three-day plateau in exercise T_{re} (no change in T_{re} in the last 20 minutes of a trial) was used as evidence of complete acclimation.

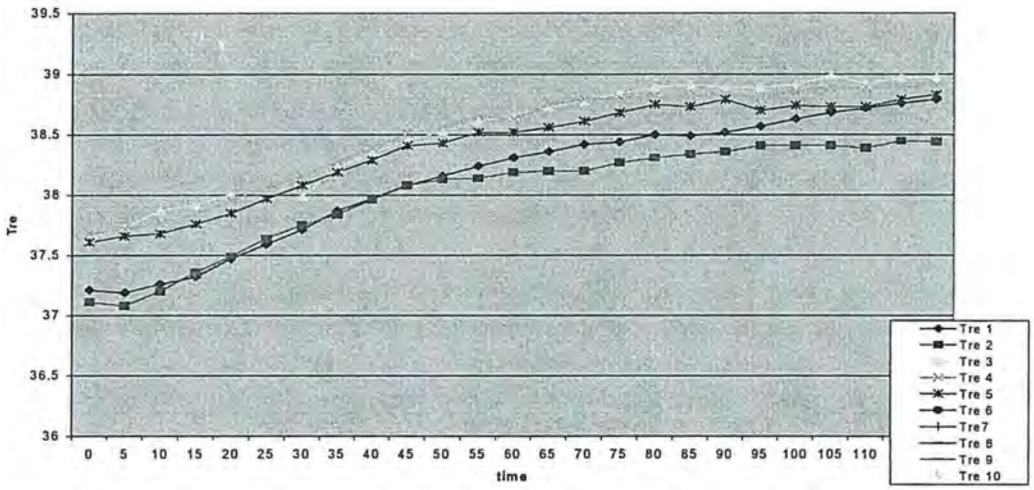

Figure 1. T_{re} data for one participant to indicate 3-day plateau as evidence of acclimation. Each line represents an acclimation session.

During the acclimation trials, participants were allowed and encouraged to drink water or an electrolyte-replacement beverage freely. Fluid intake was measured and recorded. During the trials, participants wore wear shorts and a t-shirt (and/or a sports bra for women).

Methods for Year 1: Decay of Acclimation

Participants began the study. Two of the participants withdrew early (after one and five trials) due to the unanticipated rigor of the trials and one participant w3as disqualified by the study physician. Thirteen healthy adults (seven men and 6 women) completed the experimental trials. The average and standard deviation of their physical characteristics by gender are presented in Table 1.

Table 1. Demographic data for year 1 participants (Mean ± standard deviation)

Participants	Age	Ht (m)	Wt (kg)	BSA (m^2)	Peak VO_2 (L)
Women (n=6)	26.7 ± 4.7	1.6 ± 0.07	65.6 ± 19.2	1.7 ± 0. 2	2.4 ± 0.7
Men (n=7)	33.6 ± 8.3	1.8 ± 0.05	89.3 ± 13.1	2.06 ± 0.2	3.4 ± 0.8
Total (n=13)	30.4 ± 7.5	1.7 ± 0.1	78.4 ± 19.7	1.9 ± 0.3	2.9 ± 0.9

Experimental Protocol

After the acclimation period, participants were requested to refrain from strenuous physical activity in the heat for the decay period. Participants were randomly assigned to one of two groups. Participants in group A underwent one 2-hour session in the climatic chamber at 1, 3, and 5 weeks post-acclimation to evaluate decay of acclimation. Group B underwent one 2-hour session in the climatic chamber at 2, 4, and 6 weeks post-acclimation. Two weeks between heat exposures was used to minimize re-induction of acclimation.

Methods for Year 2: Time for Re-acclimation

Participants

Fifteen participants began this phase of the study. Two of the participants withdrew early (after three and four trials) due to the unanticipated rigor of the trials and two participants became ill during the course of the trials. (The illness was not related to the study protocol.) Eleven healthy adults (eight women and three men) completed the trials. The average and standard deviation of their physical characteristics by gender are provided in Table 2.

Table 2. Demographic data for year 2 participants (Mean ± standard deviation)

Participants	Age	Ht (m)	Wt (kg)	BSA (m^2)	Peak VO_2 (L)
Women (n=8)	26.3 ± 5.7	1.6 ± 0.10	67.6 ± 13.7	1.7 ± 0. 2	2.07 ± 0.5
Men (n=3)	32.7 ± 12.5	1.8 ± 0.07	102.0 ± 17.3	2.2 ± 0.2	3.20 ± 1.2
Total (n=11)	28.04 ± 7.9	1.7 ± 0.10	76.9 ± 21.2	1.9 ± 0.3	2.40 ± 0.9

Experimental Protocol

After the acclimation period, participants were randomly assigned to one of two groups. Group A was asked to refrain from physical activity in the heat for a period equal to an average of 1/3 complete loss of acclimation (2 weeks) as determined from Year 1 data. Group B was asked to refrain from physical activity in the heat for a period equal to 2/3 complete loss of acclimation (4 weeks) as determined from Year 1 data.

Each group began the acclimation process until core temperature reached a plateau evidenced by no change T_{re} in the last 20 minutes of a trial for 3 days. The assigned time for full re-acclimation was the earliest of the three days.

Results

Results for Year 1: Decay of Acclimation

A 2-way ANOVA was performed on heart rate, T_{re} and sweat loss. (13 participants by 7 acclimation periods). There were no significant differences in heart rate or sweat loss among the trials ($p>0.05$). Although not significant, there was a trend toward increased T_{re} ($p=0.07$) with increasing time away from the heat. Table 3 provides the means and standard deviation for heart rate, T_{re} and sweat loss by acclimation trial.

Table 3. Physiological variables for year 1 (Mean ± standard deviation)

	Heart Rate (bpm)	Core temperature (°C)	Sweat loss (L/hr)
Beginning of acclimation (n=13)	144±17	38.06±0.34	0.94±0.34
End of acclimation (n=13)	140±16	38.25±0.29	0.95±0.30
Decay 1 week (n=6)	122±8	37.95±0.13	1.24±0.25
Decay 2 weeks (n=6)	150±12	38.46±0.47	1.14±.023
Decay 3 weeks (n=7)	141±21	38.18±0.46	1.08±0.32
Decay 4 weeks (n=5)	144±16	38.42±0.24	1.02±0.48
Decay 5 weeks (n=6)	139±19	38.26±0.28	1.02±.032
Decay 6 weeks (n=5)	159±18	38.70±0.30	1.07±0.43

To determine the time for acclimation to be lost, participants' data were plotted over time. Figure 2 shows the ending T_{re} for during the acclimation and decay phases of the study. Note time is scaled in days, where 0 has been set to the last day of the acclimation phase for each participant. Although there is variability among individuals, there is a general tendency for ending T_{re} to decrease during the acclimation phase and to increase during the decay phase.

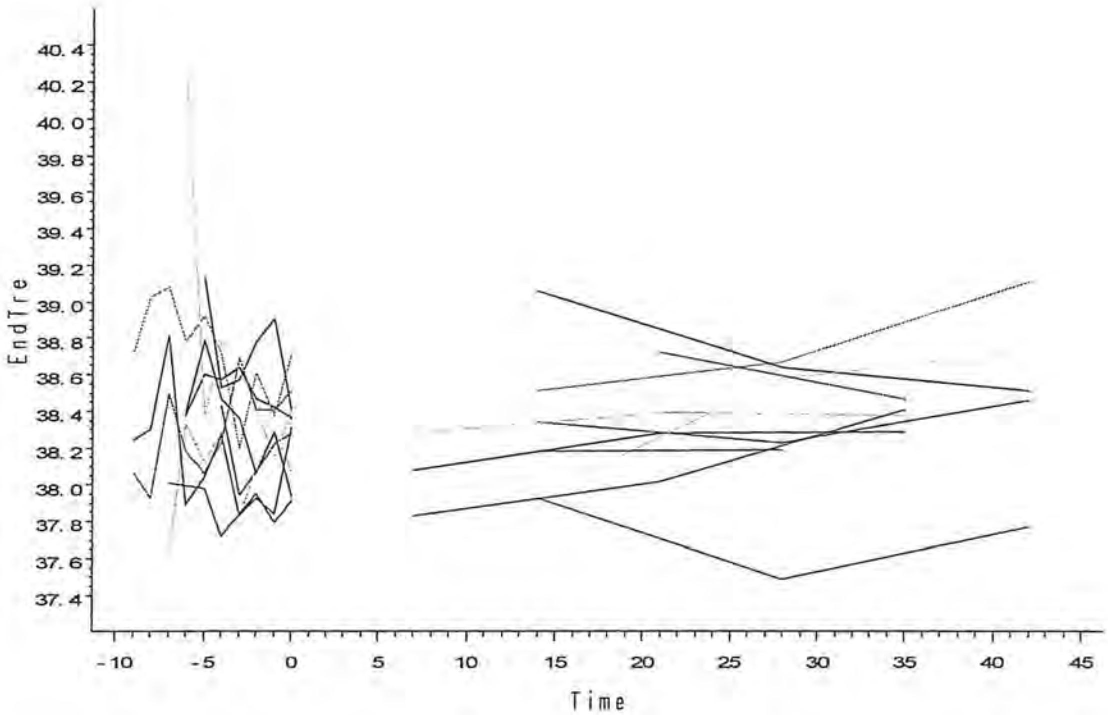

Figure 2. Ending T_{re} during acclimation and decay of acclimation. Time 0 = completion of initial acclimation

The expected trends during the acclimation and decay phases were analyzed using a hierarchical linear model using restricted maximum likelihood estimation. The obtained trend line is shown graphically as a bold solid line in Figure 3. Note ending T_{re} drops as expected during the acclimation phase and rise as expected during the decay phase.

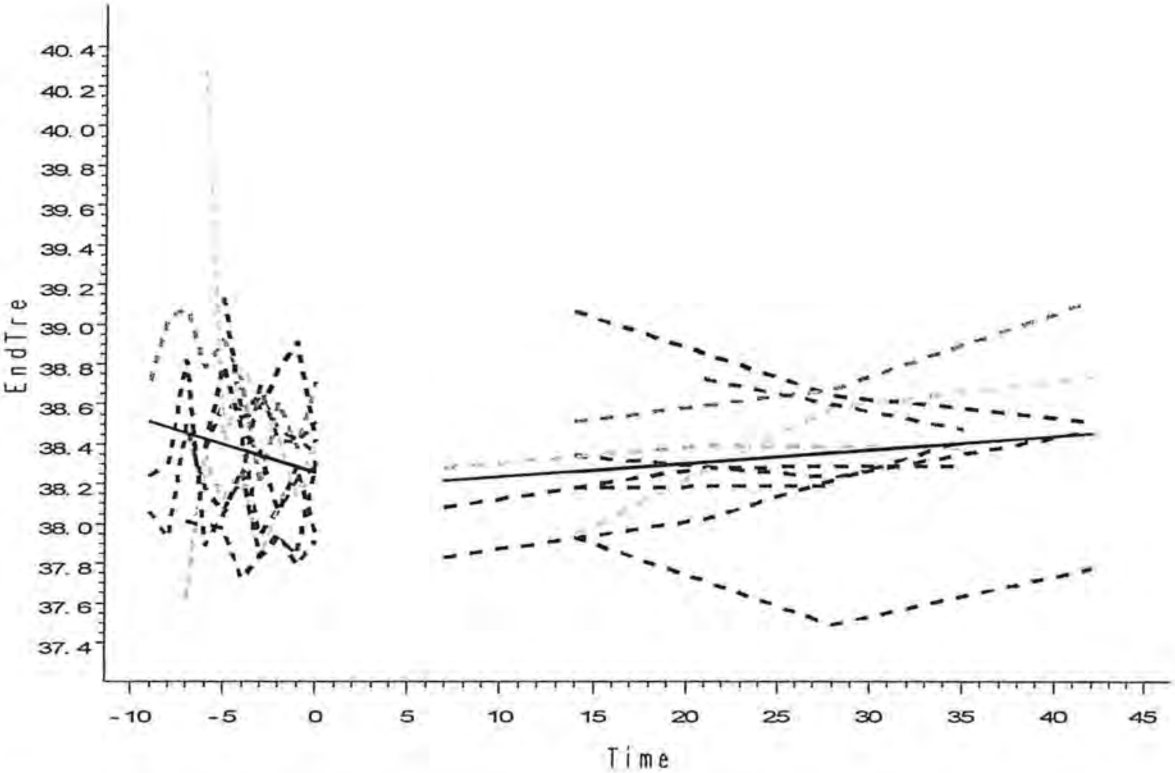

Figure 3. Trend of ending T_{re} for acclimation and decay of acclimation. Time 0 = completion on acclimation

To estimate the time for acclimation to be lost, we considered first the time it took individuals to become acclimated (Mean = 5.8 ±0.6 days). Using the mean time for acclimation and the estimates of the coefficients from the hierarchial linear model, it is estimated that on average acclimation is lost in 42.5 days (or 6 weeks). This is shown graphically in Figure 4, which shows the trend lines, the typical average start time, and the point in the decay phase where the predicted end T_{re} is equal to what the end T_{re} was at the average start time.

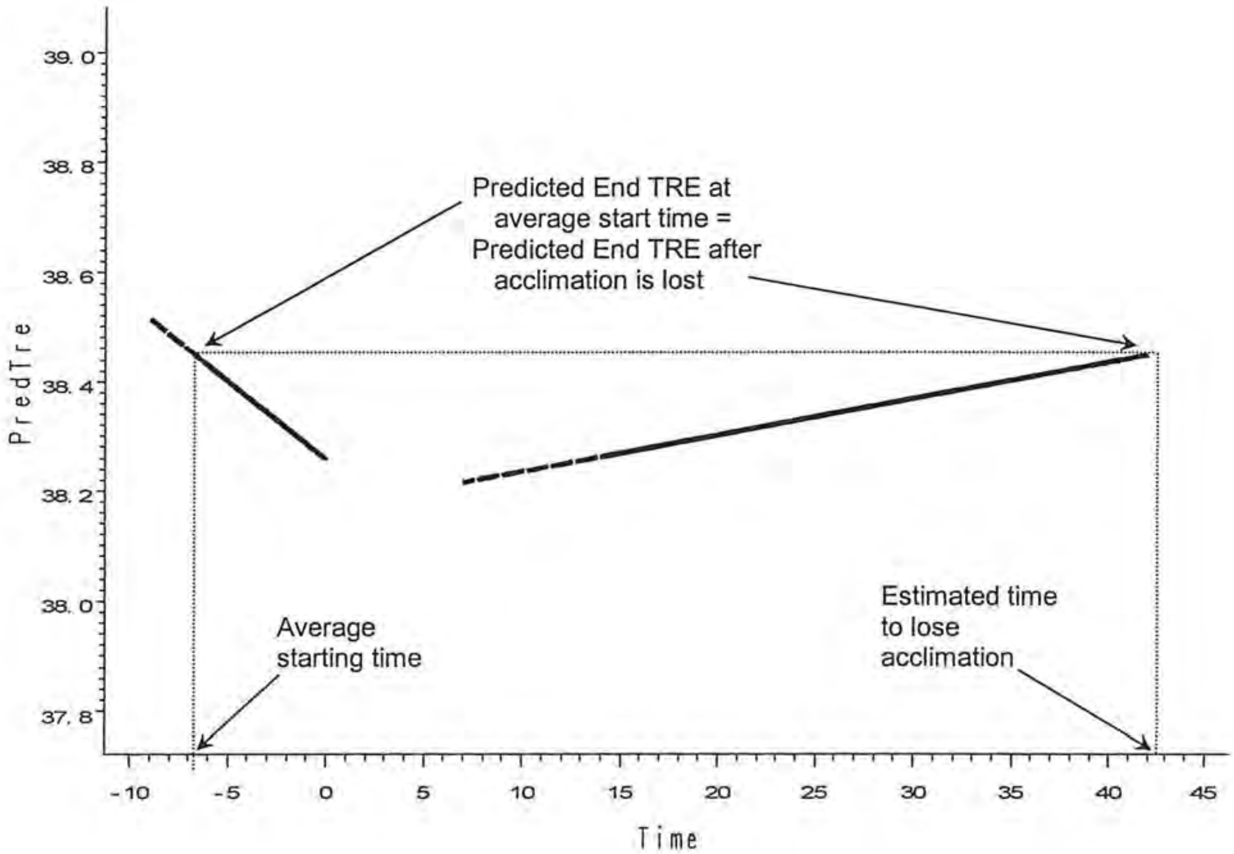

Figure 4. Estimated time for decay of acclimation.

Results for Year 2: Time for Re-acclimation

There were no significant differences in days for acclimation or re-acclimation between the groups. The average days for acclimation and re-acclimation are presented in Table 4.

Table 4. Days for acclimation and re-acclimation by re-acclimation group (Mean±standard deviation)

	Days to acclimate	Days to re-acclimate
2-week re-acclimation group	6.5±0.5	3.8±0.4
4-week re-acclimation group	6.3±0.4	5.3±0.6
Total	6.4±0.4	4.4±0.5

The study employed a repeated measures design with T_{re}, heart rate and sweat rate as the dependent variables. The dependent variables were measured during acclimation and during re-acclimation. Physiological variables during acclimation and re-acclimation are shown in Table 5. There were no differences between the trials (acclimation and re-acclimation, $p>0.05$). There were differences between re-acclimation groups in average sweat loss (L/hr) and ending heart rate ($p<0.05$). There were no trial by re-acclimation group interactions ($p>0.05$).

Table 5. Physiological responses during acclimation and re-acclimation (Mean±standard deviation)

	2 week group		4-week group		Total	
	Acclimation	Re-acclimation	Acclimation	Re-acclimation	Acclimation	Re-acclimation
Sweat loss (L/hr)	0.68±0.24	0.72±0.18	1.07±0.23	1.07±0.33	0.84±0.30	0.85±0.30*
End HR (bpm)	140.1±10.9	143.5±9.7	135.3±7.6	124.3±7.1	138.2±9.6	135.8±13.0*
End T_{re} (°C)	38.31±0.26	38.12±0.23	38.33±0.24	38.14±0.38	38.32±0.24	38.12±0.28

* Significantly different between groups, $p < 0.05$

Physiological variables were plotted and were analyzed for initial comparability of the two groups in terms of physiological variables. The trajectories of the participants was examined.

Heart Rate

Initial acclimation period. To examine the initial comparability of the two groups, heart rate was plotted for each participant as a function of time during the initial acclimation period (Fig.5). There was considerable overlap between the trajectories of those who would be assigned to the two-week re-acclimation group (shown as solid lines) and those who would be assigned to the four-week re-acclimation group (shown as dashed lines).

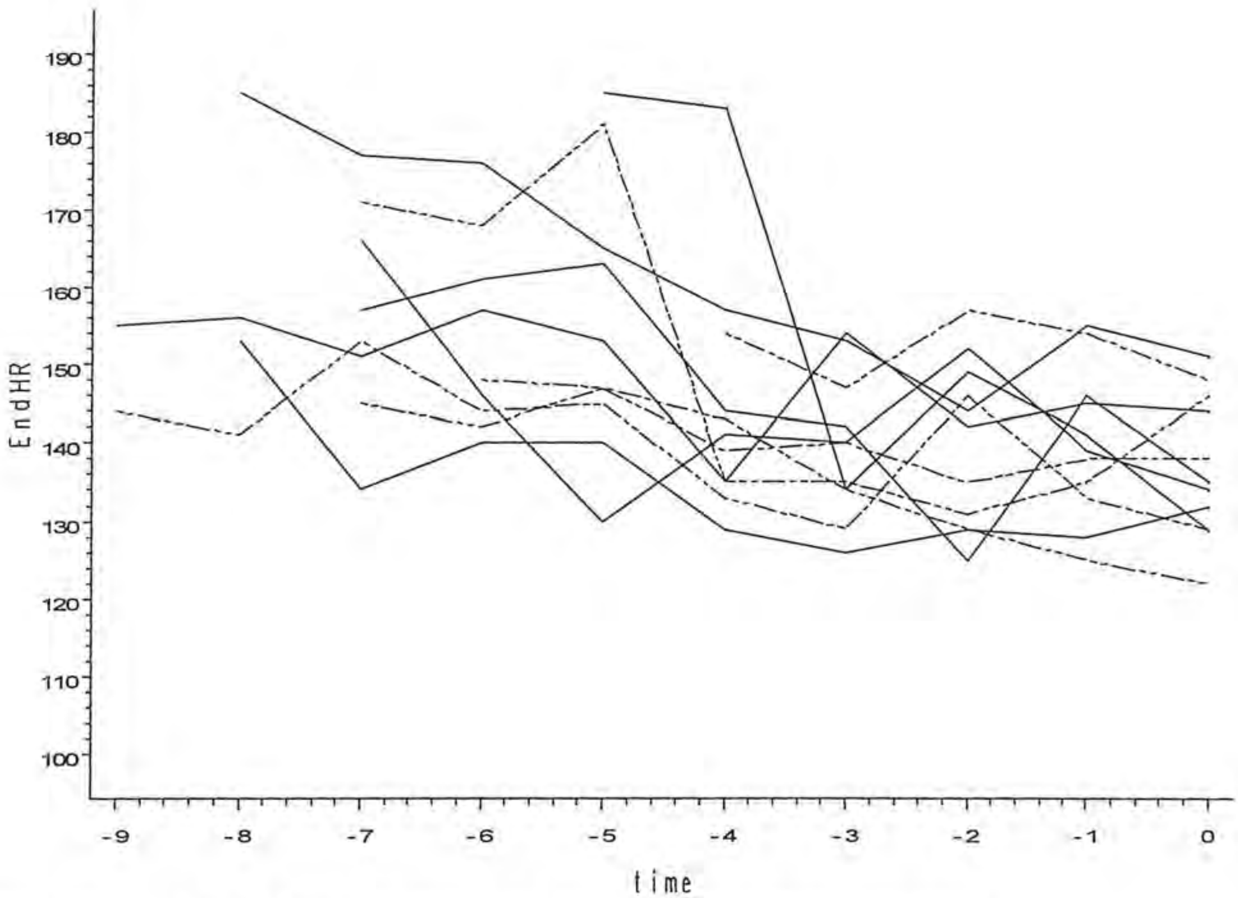

Figure 5. Ending heart rate shown as a function of time during the initial acclimation period. Solid lines represent individuals that were assigned to the two-week re-acclimation group, where dashed lines represent individuals who were assigned to the four-week re-acclimation group.

The trajectories were more formally compared using multilevel modeling techniques. The model was estimated using restricted maximum likelihood estimation. None of the coefficients indexing differences between the two groups were statistically significant.

This was expected because the assignment to the 2-week or 4-week re-acclimation group was made randomly.

Re- acclimation period. The analyses conducted during the initial acclimation period were also conducted to examine the trajectories of participants during the re-acclimation period. Ending heart rate was plotted for each participant as a function of time. As seen in Figure 6, there was still overlap between the two groups, but the overlap was not as great. Note those in the 2-week group (solid lines) tend to show more change during the re-acclimation period than those in the 4-week group (dashed lines).

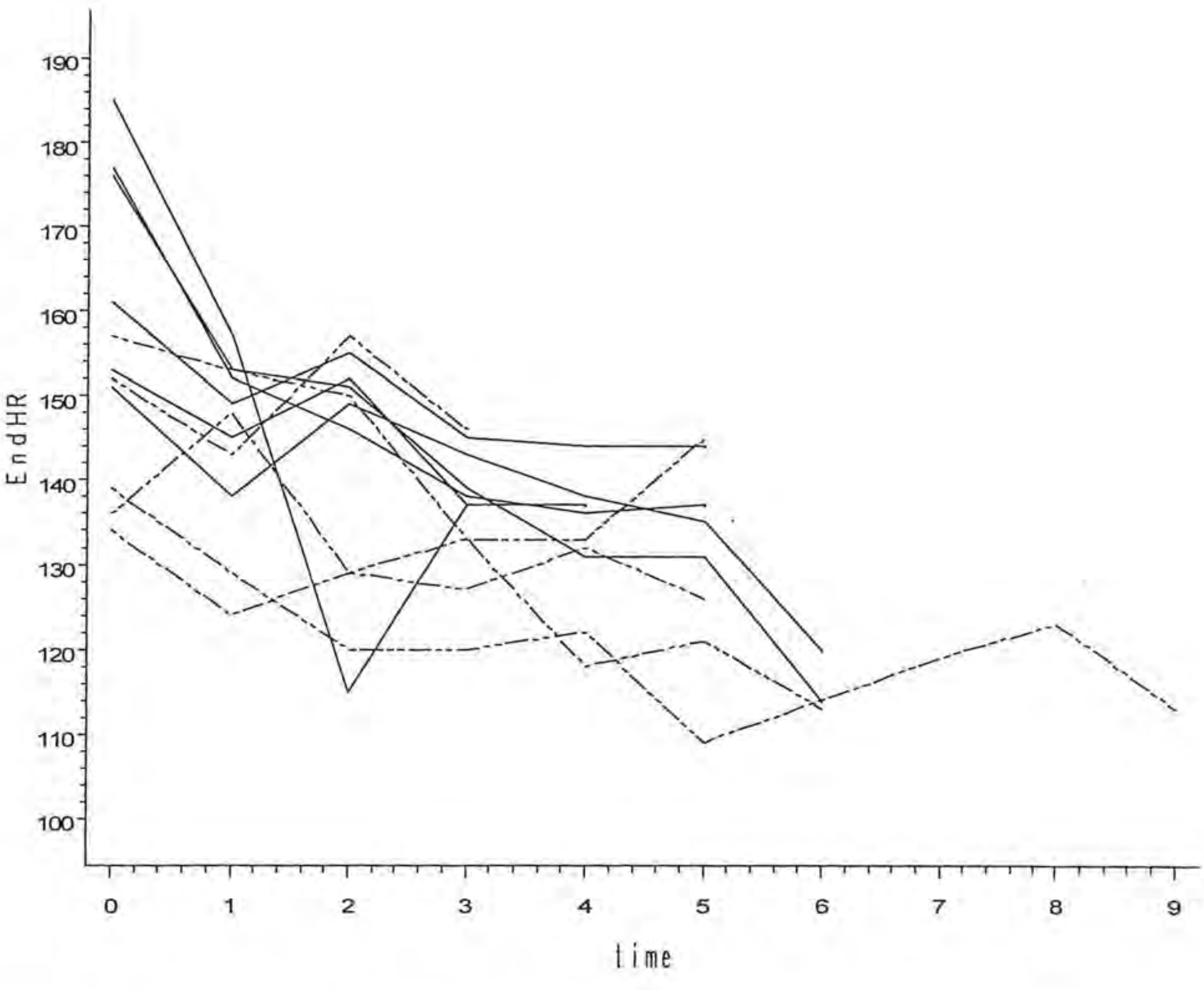

Figure 6. Ending heart rate shown as a function of time during the re- acclimation period. Solid lines represent individuals that were assigned to the two-week re-acclimation group, where dashed lines represent individuals who were assigned to the four-week acclimation group.

The trajectories were more formally compared using the previously described multilevel model. A statistically significant difference was found in the average trajectories of the two groups. The 2-week re-acclimation group had an ending heart rate that was 19 bpm higher during the re- acclimation phase ($p = 0.0075$).

The average trajectory for each group is superimposed on the graph in Figure 7. It can be seen here that the difference is most pronounced at the beginning of the acclimation phase, and that the average trajectories meet after six days.

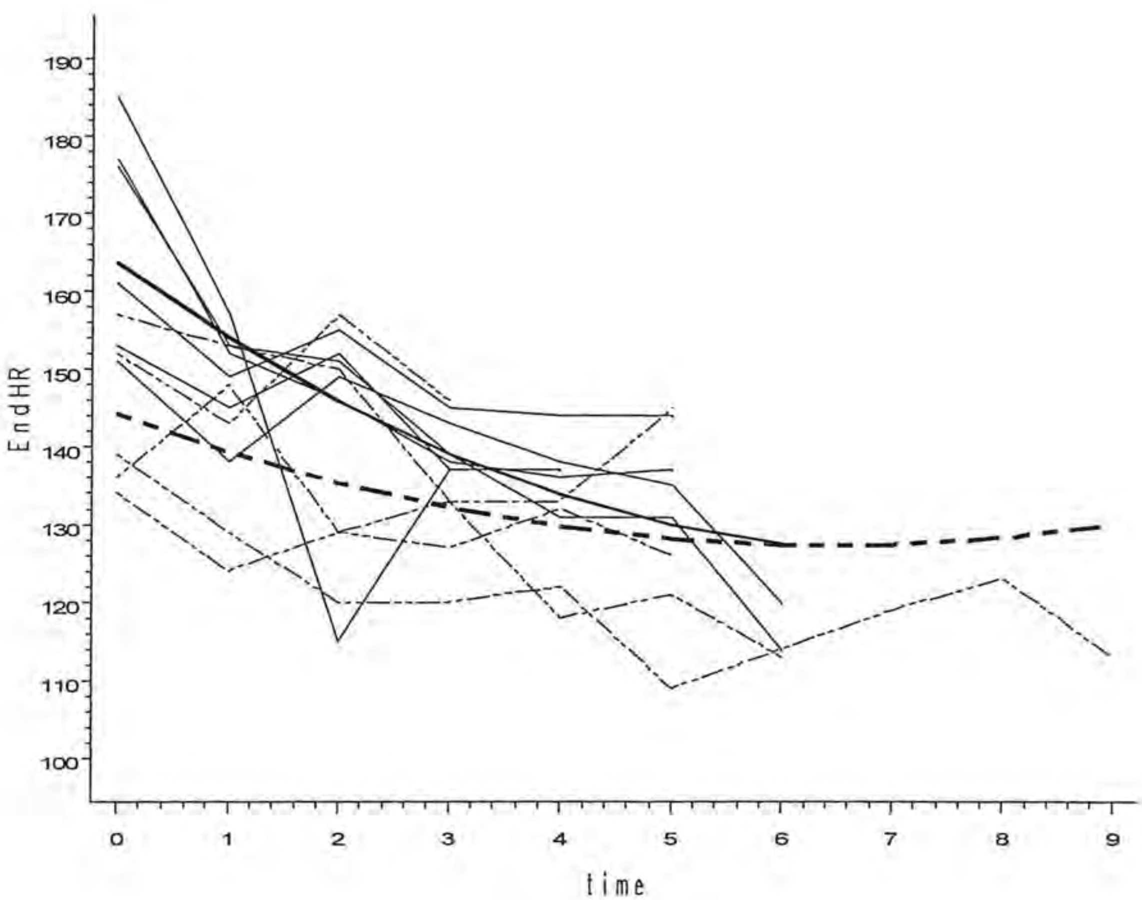

Figure 7. Ending heart rate shown as a function of time during the re- acclimation period. Solid lines represent individuals that were assigned to the two-week acclimation group, where dashed lines represent individuals who were assigned to the four-week acclimation group. The darker lines represent the average trajectory of each group.

End T_{re}

Initial acclimation period. To examine the initial comparability of the two groups of participants, the end T_{re} was also plotted for each individual as a function of time during the initial acclimation period. Again there was considerable overlap between the trajectories of those who would be assigned to the two-week group (shown as solid lines) and those who would be assigned to the four-week group (shown as dashed lines). The trajectories were compared using the multilevel models previously described. No statistically significant differences were found between the two groups of trajectories.

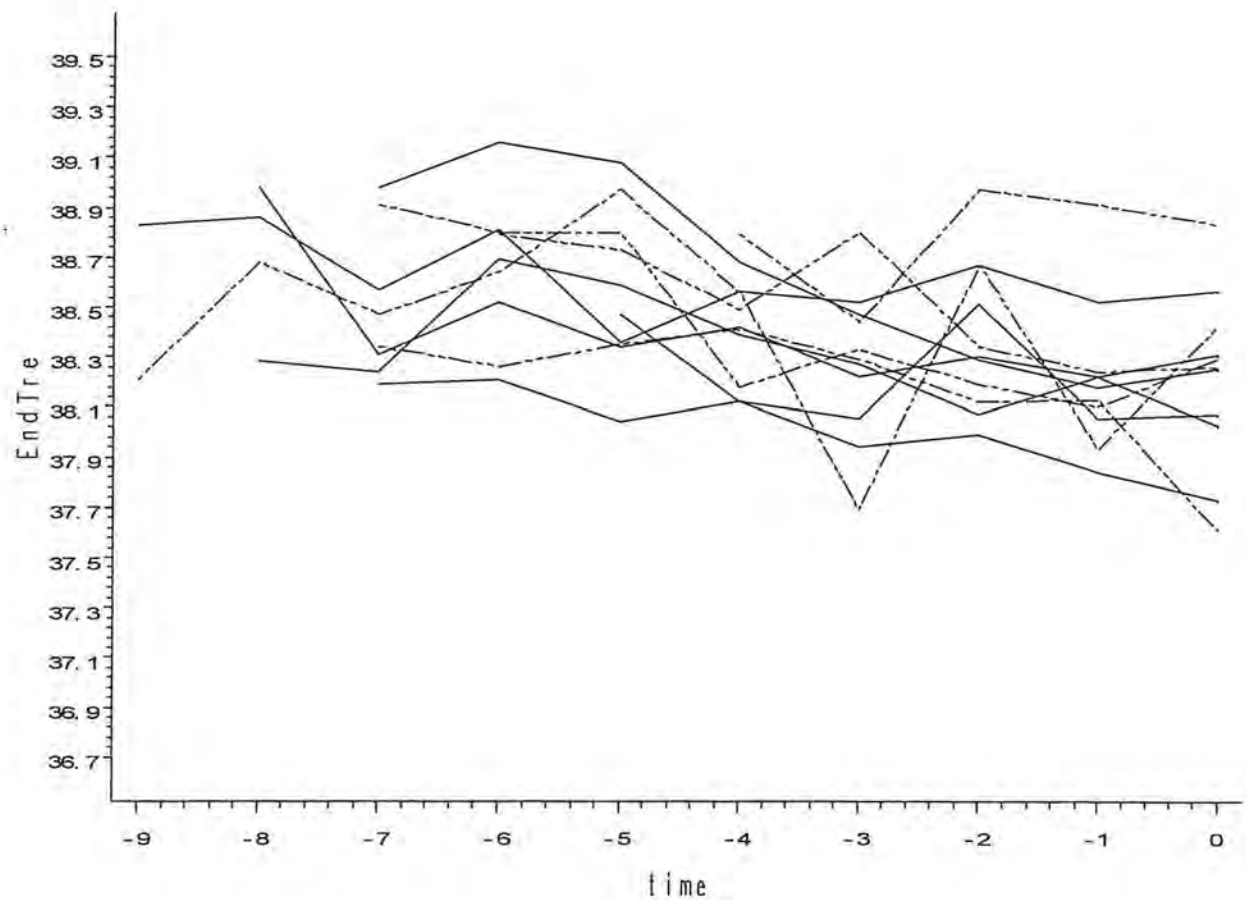

Figure 8. Ending T_{re} shown as a function of time during the initial acclimation period. Solid lines represent individuals that are later assigned to a two-week group, where dashed lines represent individuals who are later assigned to a four-week group.

Re- acclimation period. The analyses conducted during the initial acclimation period were also conducted to examine the trajectories of participants during the re-acclimation period. Ending T_{re} was plotted for each participant as a function of time. As seen in Figure 9, there was still overlap between the two groups. Note those in the 2-week re-acclimation group (solid lines) tend to show more change during the re-acclimation period than those in the 4-week re-acclimation group (dashed lines).

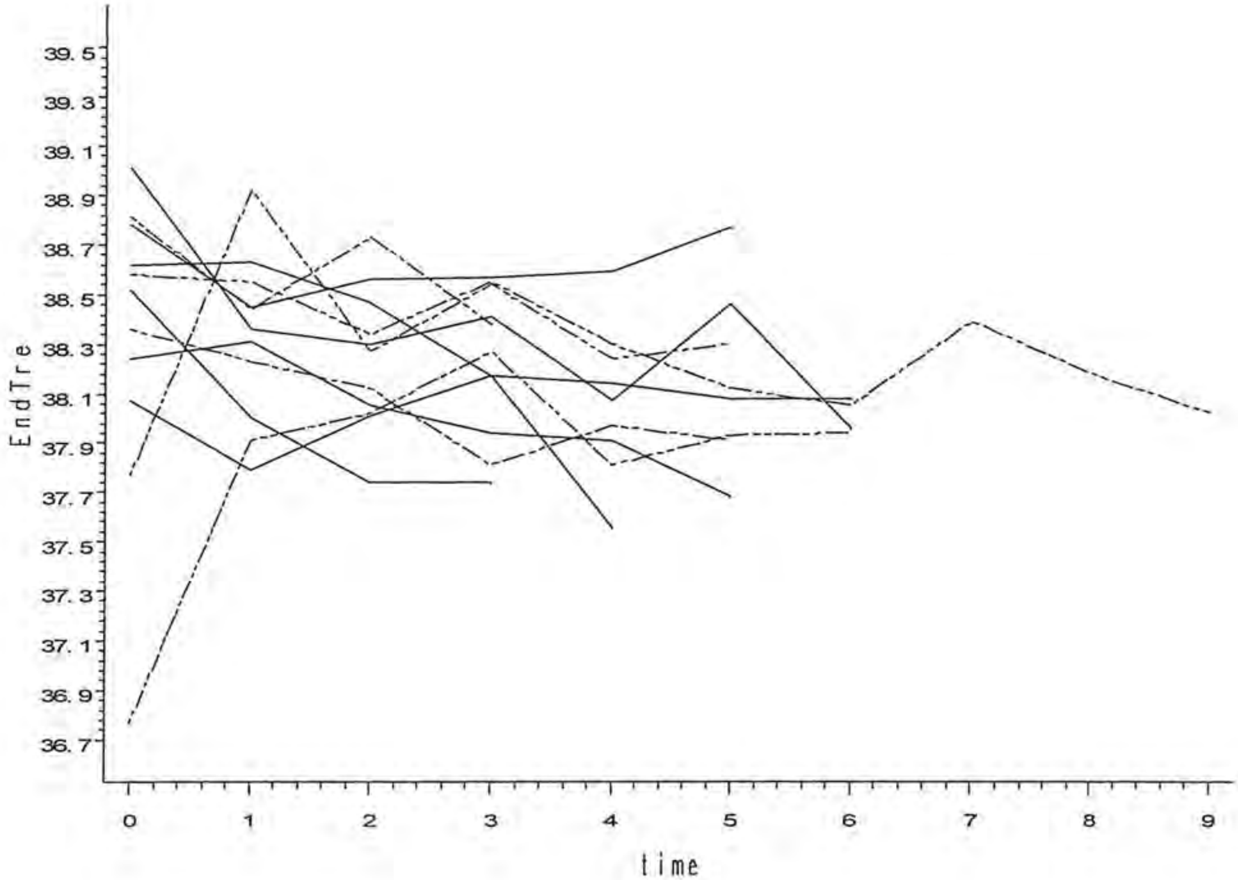

Figure 9. Ending T_{re} shown as a function of time during the re- acclimation period. Solid lines represent individuals that were assigned to the two-week acclimation group, where dashed lines represent individuals who were assigned to the four-week acclimation group.

The previously described multilevel modeling analyses were used to compare the trajectories of the two groups. Time was centered so zero corresponded to the first observation of re-acclimation. A statistically significant difference was found in the average trajectories of the two groups. The 2-week re-acclimation group had a linear component that showed a faster decrease in ending T_{re} than the 4-week re-acclimation group ($p = 0.0407$).

The average trajectory for each group is superimposed on the graph in Figure 10. It can be seen that the difference is most pronounced at the beginning of the re-acclimation phase, and is primarily due to low ending T_{re} at the beginning of re-acclimation of two participants in the 4-week re-acclimation group.

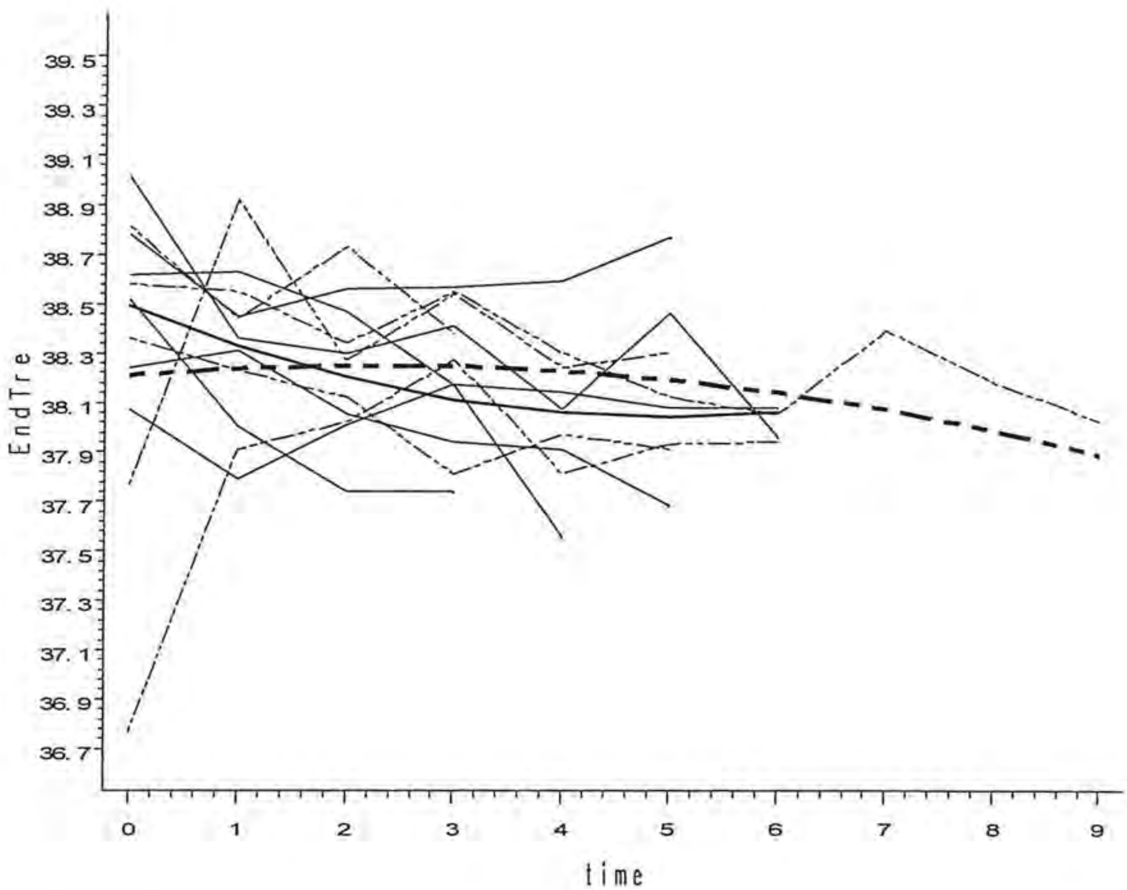

Figure 10. Ending T_{re} shown as a function of time during the re- acclimation period. Solid lines represent individuals that were assigned to the two-week group, where dashed lines represent individuals who were assigned to the four-week group. The darker lines represent the average trajectory of each group.

Discussion

Work in a warm or hot environment coupled with high metabolic loads and/or protective clothing can induce considerable heat strain. Sound acclimation programs can decrease signs of heat strain by inducing physiological changes such as improved circulatory efficiency and sweating capacity to enhance thermoregulation. Once acclimated, workers will maintain the physiological adaptations as long as they continue work in the heat. NIOSH (12) recommends an acclimation program of approximately 5 days for workers with no experience in the heat. Physiological markers of acclimation include lower heart rate and T_{re} for a given workload. As heart rate may be influenced by variables other than heat strain, a plateau in T_{re} has been suggested as the major criteria for complete acclimation (20,24). Armstrong (5) suggests that physiological adaptations take as little as three or as much as 14 days of exposure to heat stress. A number of other researchers suggest that a plateau in Tre occurs with seven days of acclimation (6,8,10,14,17). These results are similar to the results of our study. Based on a 3-day plateau in Tre, acclimation in years 1 and 2 of our study was complete in approximately 8 days suggesting that acclimation can occur in 6 days of exposure to hot-dry conditions.

Decay of Acclimation

Workers may be absent due to plant shut-down, vacation, and/or injury or illness. Adaptations of acclimation are lost if work in the heat is discontinued. The rate of the decay of these adaptations is uncertain. A review of early studies by Givoni and Goldman (7) suggests that the decay rate is approximately 1 day for each two days away from the heat. This is the basis for the recommendations by OSHA (16) for two weeks acclimation. However, there are a number of shortcomings of these studies. A number of these studies had shortened or incomplete acclimation periods (9,25). Based on this data, it seems uncertain that these people were fully acclimated. The present study used a plateau in T_{re} to establish acclimation rather than a set number of days for acclimation. Also, limited decay periods of 6 or 28 days were used by other studies. The present study ascertained the decay of acclimation for a total of 6 weeks in two week increments. Two weeks between heat exposures were used to minimize re-induction of acclimation. Further, early studies used fit participants in their studies (2,17,25). Pandolf (17) reported a shorter acclimation for those with the highest aerobic capacity. Our participants were only moderately fit. In addition, these experiments took place in Florida while most previous research examining the decay of acclimation took place in cooler conditions (17,24). The participants in the present study were requested to refrain from physical activity in the heat during the study period. However, a lifestyle questionnaire was not used to ascertain the level of activity before or during the study period, so the extent of exposure to heat during the decay period cannot be accurately determined. Informal interviews of the participants suggest that they did refrain from moderate or vigorous physical activity in the heat, but continued with normal daily activity. As many of the participants were students, normal daily activities included riding their bikes or walking.

Time for Re-acclimation

When workers may be absent from the heat, some degree of acclimation may be lost. These absences will require some re-acclimation. Some guidance for re-acclimation is available. For instance, OSHA (16) recommendations call for a 5-day re-acclimation period for workers returning from an absence of two weeks or more. A limited number of studies have evaluated re-acclimation to heat after a period of time away from the heat (17,22,24). However, it is not certain that these studies fully acclimated their participants, subjects were merely acclimated for a certain number of days. In addition, re-acclimation did not occur after total decay of acclimation. Essentially, OSHA assumes complete loss of acclimation in two weeks. Our re-acclimation period was based on a percentage of total decay of 6 weeks as determined from the year 1 data.

Re-acclimation from a partially acclimated state is not well-articulated. It seems logical that re-acclimation from a partial loss of acclimation may be shorter, and that the longer the decay of acclimation, the longer the time needed for re-acclimation. However, in our small sample, there was no difference in time for re-acclimation after two weeks or four weeks absence from the heat. However, there was a practical difference with a shorter time for re-acclimation in the group that was away from the heat for two weeks versus those away from the heat for four weeks. As previously suggested, these experiments took place in Florida while participants in other studies underwent decay of acclimation in cool conditions before re-acclimation (17,24). Although the participants in the present study were requested to refrain from physical activity in the heat, only informal interviews were used to determine this.

Conclusions

Acclimation can have a positive impact on heat stress by increasing sweat rate, and decreasing heart rate and T_{re} which helps to enhance thermoregulation, reduce fatigue, at a given work rate, enhance worker productivity, and reduce heat-related injuries. However, time away from the hot environment can result in loss of the physiological adaptations of acclimation.

Decay of Acclimation

Adaptations of acclimation are not permanent and decay gradually if exercise in the heat is discontinued. The results of this project suggest that physiological adaptations of acclimation occur in approximately 6 days with moderate exercise in hot, dry conditions. As long as workers are in the heat, physiological adaptations of acclimation persist. Total loss of acclimation occurs with a 6-week absence from the heat.

Time for Re-acclimation

Previously, little information was available regarding re-acclimation after a period of decay inducing complete loss of physiological adaptations of acclimation. One-third complete loss of acclimation (2 weeks) resulted in a time for complete re-acclimation of 4 days. Two-thirds complete loss of acclimation (4 weeks) resulted in one additional day for complete re-acclimation. The average time for re-acclimation was approximately 4-5 days. A period away from the heat of 1/3 and 2/3 complete loss of acclimation resulted in essentially equivalent times for re-acclimation. However, this data should be interpreted with caution as this project took place in central Florida. Although participants were requested to refrain from physical activity in the heat, it seems reasonable to assume that participants may have retained some acclimation from normal daily activities.

References

1 American College of Sports Medicine. (2000). *ACSM's Guidelines for Exercise Tesing and Prescription (6th ed.)* Lippincot, Williams & Wilkins: New York, 97-99.

2 Adams, J.M., Fox, R.H., Grimby, G., Kidd, D.J., & Wolff, H.S. (1960). Acclimatization to heat and its rate of decay in man. *Proceedings of the Physiological Society,* 25, 26-27.

3 Aoyagi, Y., McLellan, T., & Shephard, R. (1997). Interactions of physical training and heat acclimation: The thermophysiology of exercising in a hot climate. *Sports Medicine*, 23(3), 173-201.

4 Aoyagi, Y., McLellan, T., & Shephard, R. (1995). Effects of 6 versus 12 days of heat acclimation on heat tolerance in lightly exercising men wearing protective clothing. *European Journal of Applied Physiology*, 71, 187-196.

5 Armstrong, L. E. & Maresh, C.M. (1991). The induction and decay of heat acclimatization in trained athletes. *Sports Medicine*, 12, 302-312.

6 Gill, N., Phed, B., & Sleivert, G. (2001). Effect of daily vs. intermittent exposure to heat acclimation. *Aviation Space and Environmental Medicine*, 72, 385-390.

7 Givoni, B., & Goldman, R.F. (1973). Predicting effects of heat acclimatization on heart rate and rectal temperature. *Journal of Applied Physiology,* 35,875-879.

8 Griefahn, B. (1997). Acclimation to three different hot climates with equivalent wet bulb temperatures. *Ergonomics*, 40(2), 223-234.

9 Henschel, A., Tayler, H.L., & Keys, A. (1943). The persistence of heat acclimatization in man. *American Journal of Physiology,* 140, 321-325.

10 Lim, C.L., Chung, K.K.C., & Hock, L.L.K. (1997). The effects of prolonged passive heat exposure and basic military training on thermoregulatory and cardiovascular responses in recruits from a tropical country. *Military Medicine,* 162, 623-627.

11 McArdle, W., Katch, F. & Katch, V. (2001). *Exercise Physiology: Energy, Nutrition, and Human Performance (5th ed.).* Lippincoitt, Williams & Wilkins: New York, 233.

12 National Institute for Occupational Safety and Health (NIOSH). (1986). *Working in hot environments*. Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication #86-112.

13 Nielsen, B., Strange, S., Christensen, N., Warberg, J., & Saltin, B. (1997). Acute and adaptive responses in humans to exercise in a warm, humid environment. *European Journal of Applied Physiology*, 434, 49-56.

14 Nielson, B. (1994). Heat stress and acclimation. *Ergonomics*, 37(1), 49-58.

15 Occupational Safety and Health Administration (OSHA). (1999). *OSHA Technical Manual*, Section III, Chapter 4: Heat Stress. Cincinnati, OH: U.S. Department of Labor.

16 Occupational Safety and Health Administration (OSHA). (1995). *Protecting workers in hot environments*. Cincinnati, OH: U.S. Department of Labor. OSHA Fact Sheet 95-16.

17 Pandolf, K.B., Burse, R.L., & Goldman, R.F. (1977). Role of physical fitness in heat acclimatization, decay and reinduction. *Ergonomics,* 20, 399-408.

18 Pichan, G., Sridaharan, K., Swamy, Y.V., Joseph, S., & Gautman, R.K. (1985). Physiological acclimatization to heat after a spell of cold conditioning n tropical subjects. *Aviation, Space, and Environmental Medicine*, 56, 436-440.

19 Raudenbush, S. W., & Bryk, A. S. (2002). *Hierarchical Linear Models: Applications and Data Analysis Methods (2nd Edition*). Thousand Oaks, CA: Sage Publications.

20 Sawka, M.N., Latzka, W.A., & Montain, S. J. (2001). Physiologic tolerance to uncompensable heat: intermittent exercise, field vs. laboratory. *Medicine and Science in Sports and Exercise*, 33(3), 422-430.

21 Shvartz, E., Saar, E., Meyerstein, N., & Benor, D. (1973). A comparison of three methods of acclimatization to dry heat. *Journal of Applied Physiology,* 34, 214-219.

22 Stephens, R.L. & Hoag, L. (1981). Heat acclimatization, its decay and reinduction in young Caucasian females. *American Industrial Hygiene Association Journal,* 42, 12-17.

23 Tayyari, F., Burford, C.L., & Ramsey, J.D. (1989). Guidelines for the use of systematic workload estimation. *International Journal of Industrial Ergonomics*, *4,* 61-66.

24 Williams, C.G., Wyndham, C.H., & Morrison, J.F. (1967). Rate of loss of acclimatization in summer and winter. *Journal of Applied Physiology,* 22, 21-26.

25 Wyndham, C.H., & Jacobs, G.E. (1957). Loss of acclimatization after six days of work in cool conditions on the surface of a mine. *Journal of Applied Physiology*, 11, 197-198.

Inclusion Enrollment Report

Study Title: Decay of Acclimation and Time for Re-acclimation

Total Enrollment: 31 **Protocol Number:**

Grant Number: 1 RO3 OH007836-01

PART A. TOTAL ENROLLMENT REPORT: Number of Subjects Enrolled to Date (Cumulative) by Ethnicity and Race				
	Sex/Gender			
Ethnic Category	**Females**	**Males**	**Unknown or Not Reported**	**Total**
Hispanic or Latino	3	2	0	5 **
Not Hispanic or Latino	15	11	0	26
Unknown (individuals not reporting ethnicity)	0	0	0	0
Ethnic Category: Total of All Subjects*	18	13	0	31 *
Racial Categories				
American Indian/Alaska Native	0	0	0	0
Asian	0	0	0	0
Native Hawaiian or Other Pacific Islander	0	0	0	0
Black or African American	2	2	0	4
White	16	11	0	27
More Than One Race	0	0	0	0
Unknown or Not Reported	0	0	0	0
Racial Categories: Total of All Subjects*	18	13	0	31 *

PART B. HISPANIC ENROLLMENT REPORT: Number of Hispanics or Latinos Enrolled to Date (Cumulative)				
Racial Categories	**Females**	**Males**	**Unknown or Not Reported**	**Total**
American Indian or Alaska Native				
Asian				
Native Hawaiian or Other Pacific Islander				
Black or African American				
White	3	2	0	5
More Than One Race				
Unknown or Not Reported				
Racial Categories: Total of Hispanics or Latinos**	3	2	0	5 **