THERMOREGULATION AND FLUID BALANCE IN CHILDREN
EXERCISING IN THE HEAT

A Dissertation in
Kinesiology
by
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ABSTRACT

Numerous factors could affect a child’s physical performance, subjective comfort and/or physical well-being during exercise in the heat including hydration status, degree of heat acclimatization (induced in natural environment) / acclimation (induced over a shorter period of time, often in a laboratory setting), and severity of environmental conditions. However, there is a dearth of empirically-based information examining the impact of these factors on the physiological and subjective responses of children exercising in the heat. This series of studies were designed to: 1) determine the effect of two percent exercise-heat induced dehydration (DEH) and 6% carbohydrate-electrolyte solution (CES) euhydration (EUH) compared with placebo (P) EUH on basketball skill performance in highly skilled young players; 2) determine the degree of initial natural acclimatization and artificially-induced acclimation-related changes during repeated exercise / heat bouts in 7 lean and 7 obese 9- to 12-yr-old boys during the summer months; and 3) determine the critical environmental limits for uncompensable heat stress, above which an imbalance between heat gain and heat loss forces body core temperature ($T_c$) upward for exercising, heat-acclimated lean and obese 9- to 12-yr-old boys.

The first study tested the hypotheses that CES EUH will improve and two percent DEH will impair 12- to 15-year old boys’ basketball performance compared with P EUH. Fifteen 12- to 15-yr-old boys underwent 3 separate 2-h exercise-heat exposures (double-blind, random order): 2% DEH by limiting fluid intake during exercise in the heat and basketball skill drills, EUH (no net weight change) with a 6% CES, and EUH with a flavored water P. After recovery, subjects performed an orchestrated sequence of continuous basketball drills designed to simulate a game (12-min quarters + a 10-min halftime). Performance measures which were component drills inherent to basketball included various individual and combined shooting percentages
(three-point, 15-foot, free throw shots), sprint (suicides, court widths), lateral movement (zig-zags, lane slides), and defensive drill (combining lateral and front-to-back movement) times. Compared to P (53 ± 11%) combined shooting percentage was impaired by 2% DEH (45 ± 9%; P = 0.002) and improved by CES intake (60 ± 8%; P = 0.003). Total sprint times showed a similar effect (83 ± 10 vs. 78 ± 9 vs. 76 ± 9 s; DEH vs. P vs. CES; P < 0.001 and P = 0.04, respectively). Total lateral movement times were impaired by 2% DEH (73 ± 8 vs. 68 ± 8 s; P = 0.001). CES improved total defensive drill times compared to 2% DEH (77 ± 10 vs. 82 ± 10; P = 0.006). These results suggest that deterioration in basketball skill performance accompanies 2% dehydration in skilled 12- to 15-yr-old basketball players. Additionally, EUH with a 6% CES significantly improves shooting performance and on-court sprinting over EUH with water.

The second study tested the hypotheses that obese compared to lean 9- to 12-yr-old children would: 1) be less naturally acclimatized to the heat as shown by significantly higher baseline $T_c$; and 2) display a significantly slower time course for the classic markers of acclimation (e.g., day to day decreases in exercise $T_c$ and heart rate (HR), elevations in sweating rate) during repeated days of light-to-moderate intensity exercise in a warm, humid environment. Beginning at random times during the summer, subjects underwent six 70-min exercise (30% maximal oxygen uptake ($\dot{V}O_{2\text{max}}$)) / heat exposures (38°C, 50% rh) on separate days. On day 1, obese children were less naturally acclimatized as indicated by significantly higher baseline $T_c$ (obese = 37.62 ± 0.06 vs. lean = 37.41 ± 0.06; P < 0.004). By day 6 vs. 1, significant reductions in baseline $T_c$ were evident in both groups (obese = 37.41 ± 0.04 vs. lean = 37.18 ± 0.04; both P < 0.05). Baseline $T_c$ in obese subjects by day 6 was similar to that of lean subjects on day 1. Daily reductions in exercise $T_c$ were evident in both groups (final exercising $T_c$ day 1 vs. 6; obese = 38.15 ± 0.05 vs. 37.89 ± 0.05, lean = 38.17 ± 0.09 vs. 37.72 ± 0.06°C; both P < 0.001),
occurring at a significantly slower rate in obese subjects (final exercise $T_c$ day 6 – 1; obese vs. lean = -0.26 ± 0.04 vs. -0.45 ± 0.08°C; P < 0.05). Significant reductions in exercising HR occurred in the lean but not the obese subjects by day 6 (final exercising HR day 1 vs. 6; obese = 132 ± 3 vs. 131 ± 3; P > 0.05, lean = 138 ± 3 vs. 127 ± 3 bpm; P < 0.001). These results suggest that during summer months, obese children are less naturally heat acclimatized and subsequently acclimate at a slower rate.

The third study tested the hypothesis that during light-to-moderate intensity exercise in a warm environment, the critical environments for heat-acclimated obese vs. lean 9- to 12-yr-old children will be shifted downward on a psychometric chart, toward a lower critical water vapor pressure ($P_{crit}$). The $P_{crit}$ was identified by a continuous rise in $T_c$ and was defined as the critical ambient water vapor pressure above which thermal balance could not be maintained during exercise. Seven lean and 7 obese 9- to 12-yr-old heat-acclimated boys performed 4 randomized trials each on separate days. Subjects walked continuously on a treadmill at 30% $\tilde{V}o_{2max}$ at a constant dry bulb temperature ($T_{db}$ = 34, 36, 38 or 42°C). After a 30-min equilibration period at 9 Torr, ambient water vapor pressure increased approximately 1 Torr every 5-min until a distinct breakpoint in the $T_c$ vs. time curve was evident. Compared to the lean subjects, obese subjects had significantly lower environmental limits (P < 0.03) in warm environments ($P_{crit}$, for lean vs. obese, respectively = 32.9 ± 0.7 vs. 30.3 ± 0.8 torr at $T_{db}$ = 34°C; 29.6 ± 0.6 vs. 27.2 ± 0.9 torr at $T_{db}$ = 36°C; 27.8 ± 0.6 vs. 24.7 ± 0.9 torr at $T_{db}$ = 38°C; 25.5 ± 0.7 vs. 24.5 ± 1.5 torr at $T_{db}$ = 42°C). These results suggest that separate critical environmental guidelines should be tailored to lean and obese children exercising in the heat.
# TABLE OF CONTENTS

LIST OF FIGURES ............................................................................................................... ix

LIST OF TABLES .................................................................................................................. xii

LIST OF ABBREVIATIONS .................................................................................................... xiv

ACKNOWLEDGEMENTS ........................................................................................................ xvi

Chapter 1 INTRODUCTION ................................................................................................... 1

  Background and Significance ......................................................................................... 1
  Physiological Effects of Dehydration ........................................................................... 1
  Fluid Balance and Physical Performance .................................................................. 2
  Heat-Acclimatization / Acclimation ............................................................................ 3
  Prescriptive Zone ....................................................................................................... 4

  Summary .................................................................................................................... 5

  Specific Aims and Hypotheses .................................................................................... 5

Chapter 2 REVIEW OF THE LITERATURE ............................................................................ 7

  Responses to Exercise in Adults ................................................................................. 8
  Responses to Exercise in Children ............................................................................. 11
  Responses to Thermal Stress in Adults ...................................................................... 14
  Responses to Thermal Stress in Children .................................................................. 15
  Responses to Exercise Plus Heat Stress in Adults .................................................... 16
  Responses to Exercise Plus Heat Stress in Children ................................................ 18
  Heat-Acclimatization / Acclimation ........................................................................... 21
  Fluid Balance ........................................................................................................... 22

Chapter 3 TWO PERCENT DEHYDRATION IMPAIRS AND SIX PERCENT CARBOHYDRATE DRINK IMPROVES BOYS BASKETBALL SKILLS .............................................. 25

  Introduction ................................................................................................................. 25

  Methods ....................................................................................................................... 27

    Subjects ..................................................................................................................... 27
    Experimental Design ................................................................................................. 27
    Euhydration / Dehydration Protocol ....................................................................... 28
    Recovery Period ....................................................................................................... 29
    Basketball Protocol .................................................................................................. 29
    Dehydration Trial ..................................................................................................... 31
    Measurements ......................................................................................................... 31
    Subjective Ratings .................................................................................................. 32
| Chapter 4 RESPONSES OF LEAN AND OBESE BOYS TO REPEATED SUMMER EXERCISE-HEAT BOUTS | 49 |
| Introduction | 49 |
| Methods | 51 |
| Subjects | 51 |
| Testing Procedures | 52 |
| Measurements | 53 |
| Subjective Ratings | 54 |
| Statistical Analyses | 55 |
| Results | 56 |
| Discussion | 58 |
| Beneficial Effects of Natural Acclimatization | 59 |
| Heat-Acclimation | 60 |

| Chapter 5 CRITICAL ENVIRONMENTAL LIMITS FOR EXERCISING HEAT-ACCLIMATED LEAN AND OBESE BOYS | 77 |
| Introduction | 77 |
| Methods | 78 |
| Subjects | 78 |
| Experimental Design | 79 |
| Testing Procedures | 80 |
| Measurements | 81 |
| Determination of Critical Water Vapor Pressure | 82 |
| Subjective Ratings | 83 |
| Calculations | 85 |
| Statistical Analyses | 87 |
| Results | 88 |
| Discussion | 90 |
| Psychrometric Limits | 90 |
| Subjective Responses | 93 |
| Protocol | 94 |
LIST OF FIGURES

Figure 3.1. Schematic of study design for each trial. Tread, treadmill; Bicyc, cycle ergometer; Rec, recovery; Qtr, basketball quarter; BW, body weight; Tc, core body temperature; HR, heart rate; BP, blood pressure; UR, urine sample; Vol, volume of fluid ingested; S, survey; RPE, rating of perceived exertion ..........................................................43

Figure 3.2. Schematic of continuous basketball drills protocol designed to simulate a game with four 12-min quarters and a 10-min halftime rest. The drills performed in the third quarter were the same as the first quarter (A-F), and the fourth quarter drills were the same as the second quarter (G-L). See methods for a detailed description of each drill ..........44

Figure 3.3. Responses to subjective questionnaires on 100-point scales. Only scales yielding significant effects are presented. DEH, 2% dehydration trial; P, flavored-water placebo drink trial; CES, 6% carbohydrate-electrolyte drink trial. *P < 0.05 .........................45

Figure 3.4. Boxplots of individual and combined (around the world, 3-point and free-throw shots) long-range shooting percentages relative to the P EUH. The top, bottom, and line through the middle of the box correspond to the 75th percentile (top quartile), 25th percentile (bottom quartile), and 50th percentile (median), respectively. The whiskers on the bottom extend from the 10th percentile (bottom decile) and top 90th percentile (top decile). 2% DEH, 2% dehydration prior to testing; CES, carbohydrate-electrolyte drink; mean values for the P EUH trial (the basis for each relative comparison) is shown at the right of each panel .................................................................46

Figure 3.5. Boxplots of individual, average (average of the suicides and 10-widths single performance scores), and total (sum of the suicides and 10-widths single performance scores) sprint times relative to the P EUH. The top, bottom, and line through the middle of the box correspond to the 75th percentile (top quartile), 25th percentile (bottom quartile), and 50th percentile (median) respectively. The whiskers on the bottom extend from the 10th percentile (bottom decile) and top 90th percentile (top decile). 2% DEH, 2% dehydration prior to testing; CES, carbohydrate-electrolyte drink; mean values for the P EUH trial (the basis for each relative comparison) is shown at the right of each panel ...47

Figure 3.6. Boxplots of individual, average (average of the zigzags and lane slides single performance scores), and total (sum of the zigzags and lane slides single performance scores) lateral movement times relative to the P EUH. The top, bottom, and line through the middle of the box correspond to the 75th percentile (top quartile), 25th percentile (bottom quartile), and 50th percentile (median) respectively. The whiskers on the bottom extend from the 10th percentile (bottom decile) and top 90th percentile (top decile). 2% DEH, 2% dehydration prior to testing; CES, carbohydrate-electrolyte drink; mean values for the P EUH trial (the basis for each relative comparison) is shown at the right of each panel ........................................48
Figure 4.1. Schematic of the experimental design for each trial. HR, heart rate; Tc, body core temperature; BP, blood pressure; BW, body weight; US, urine sample; Vol, volume of fluid ingested; RPE, rating of perceived exertion; TS, thermal sensation; Vo2, oxygen consumption; R1, rest period 1; R2, rest period 2 ............................................................70

Figure 4.2. Responses to the Physical Activity and Sports Competence subscales of the Physical Self Description Questionnaire on a 6-point true-false scale where 1 = “false”, 2 = “mostly false”, 3 = “more false than true”, 4 = “more true than false”, 5 = “mostly true”, and 6 = “true”. Only statements yielding significant effects are presented. Each subscale was comprised of 6 statements and the average of the 6 scores represents the overall average for that subscale. *Significant group difference at P < 0.05 ...............................71

Figure 4.3. Time course of mean Tc response of 7 lean and 7 obese 9- to 12-yr-old boys during repeated exercise-heat bouts in the summer months. Exercise at 30% Vo2max alternated between a treadmill and bike for 3 20-min bouts interspersed with 5-min rest periods at 38°C and 50% rh. Values are means ± SE. Bas, Baseline; Rec, Recovery. A (lean boys Tc, day 1 and day 6) and B (lean boys Tc, all 6 days): *P < 0.001 between day 1 and day 6 for lean boys. C (obese boys Tc, day 1 and day 6) and D (obese boys Tc, all 6 days): ‡P < 0.001 between day 1 and day 6 for obese boys ........................................................73

Figure 4.4. Time course of mean HR response of 7 lean and 7 obese 9- to 12-yr-old boys during repeated exercise-heat bouts in the summer months. Exercise at 30% Vo2max alternated between a treadmill and bike for 3 20-min bouts interspersed with 5-min rest periods at 38°C and 50% rh. Values are means ± SE. Bas, Baseline; Rec, Recovery. A (lean boys HR, day 1 and day 6) and B (lean boys HR, all 6 days): *P < 0.001 between day 1 and day 6 for lean boys. C (obese boys HR, day 1 and day 6) and D (obese boys HR, all 6 days): No significant differences between days ................................................................75

Figure 5.1. A representative critical water vapor pressure (Pcrit) test illustrating the typical time course of body core temperature (Tc), heart rate (HR), and mean skin temperature (Tsk) responses to exercise and rising ambient water vapor pressure (Pa). Subjects walk continuously on a treadmill at 30% Vo2max at a constant dry bulb (38°C in this test). After a 30-min equilibration period at 9 Torr, Pa increases approximately 1 torr every 5-min. Tc which is proportional to the work load and independent of ambient conditions increases to a steady state. Upon reaching a critical environment, Tc begins to rise again and a distinct breakpoint in the Tc vs. time curve is evident. Pilot testing determined that there is a 2-min lag in the ingestible temperature sensor response time compared to esophageal temperature. Therefore, the Pa 2-min before the inflection point was defined as the Pcrit, which was 27 torr in this example. Approximately 10 to 15-min prior to the Tc inflection point, an upward rise in HR was evident in all tests ........................................103
Figure 5.2. Critical environmental limits on a standard psychrometric chart. Values are means ± SE for 7 lean and 7 obese subjects at 34, 36 and 38°C and 7 lean and 5 obese subjects at 42°C. Compared to lean subjects, obese subjects consistently had significantly lower critical water vapor pressure ($P_{\text{crit}}$) values in each warm environment. *Significant group difference at $P < 0.03$
LIST OF TABLES

Table 3.1. Subject characteristics. $\dot{V}O_{2\max} =$ maximal oxygen consumption, $^a$ triceps and calf equation; Slaughter et al. (151), $^b$ number of years subject reported playing competitive basketball, $^c$ extrapolated from submax peak ..........................................................41

Table 3.2. Physiological and RPE variables. Values are mean ± SD at end of each time period. CES, 6% carbohydrate-electrolyte drink trial; P EUH, flavored-water placebo drink trial; DEH, 2% dehydration trial; HR, heart rate; $T_c$, core body temperature; MAP, mean arterial pressure; RPE, rating of perceived exertion; SL, sweat loss; $U_{\text{vol}}$, urine volume; $U_{\text{col}}$, urine color; $U_{\text{sg}}$, urine specific gravity; $U_{\text{osmol}}$, urine osmolality. *$P < 0.05$, DEH vs. P EUH. †$P < 0.05$, CES vs. DEH ...............................................................42

Table 4.1. Subject characteristics by group. Values are means ± SE. $A_D$, DuBois surface area; $\dot{V}O_{2\max}$, maximal aerobic capacity. *Significantly different from lean boys, $P < 0.05$ ..66

Table 4.2. Baseline, final exercise and change in $T_c$ by day of acclimation. Values are means ± SE for 7 lean and 7 obese subjects. $T_c$, body core temperature; $\Delta T_c =$ Final Exercise $T_c$ – Baseline $T_c$. * Significant group difference at $P < 0.05$. †Significantly different from day 1 at $P < 0.05$ ......................................................................................................................67

Table 4.3. Sweating rate during repeated exercise-heat bouts by day of acclimation. Values are means ± SE for 7 lean and 7 obese subjects. *Significant group difference at $P < 0.01$ ..68

Table 4.4. Subjective responses to repeated exercise-heat bouts by day of acclimation. Values are means ± SE for 7 lean and 7 obese subjects. RPE, rating of perceived exertion; TS, thermal sensation. *Significant group difference at $P < 0.05$. †Significantly different from day 1 at $P < 0.05$ ...............................................................................................................69

Table 5.1. Subject characteristics by group. Values are means ± SE. $\dot{V}O_{2\max}$, maximal aerobic capacity; $A_D$, DuBois surface area. *Significantly different from lean boys, $P < 0.05$ ....97

Table 5.2. Calculated heat balance variables in each critical environment. Values are means ± SE for 7 lean and 7 obese subjects at 34, 36 and 38°C and 7 lean and 5 obese subjects at 42°C. $M_{\text{net}}$, net metabolic heat production; $R+C$, dry heat exchange via radiation and convection; $S$, heat storage; $E_{\text{sk}}$, evaporative cooling from the skin; $E_{\text{req}}$, required evaporation to maintain heat balance; $w$, % skin wettedness, calculated as $E_{\text{req}}/E_{\max}$. *Significant group difference at $P < 0.05$ ..........................................................................................................................98

Table 5.3. Sweating rate. Values are means ± SE for 7 lean and 7 obese subjects at 34, 36 and 38°C and 7 lean and 5 obese subjects at 42°C. *Significant group difference at $P < 0.05$ ..........................................................................................................................99
Table 5.4. Results from the determination of critical environmental limits and water vapor pressure gradients. Values are means ± SE for 7 lean and 7 obese subjects at 34, 36 and 38°C and 7 lean and 5 obese subjects at 42°C. \( P_{\text{crit}} \), the critical water vapor pressure; \( T_{\text{wbcrit}} \), critical wet bulb temperature; \( RH_{\text{crit}} \), critical relative humidity; \( \text{WBGT}_{\text{crit}} \), critical wet bulb globe temperature, \( P_{s,sk} - P_a \); the gradient between saturated water vapor pressure of the skin and the air at the critical point. *Significant group difference at \( P < 0.04 \) ............................................................................................................................100

Table 5.5. Subjective responses. Values are means ± SE for 7 lean and 7 obese subjects at 34, 36 and 38°C and 7 lean and 5 obese subjects at 42°C. RPE, rating of perceived exertion; TS, thermal sensation; Critical, critical environmental threshold. *Significant group difference at \( P < 0.05 \) ............................................................................................................................101

Table 5.6. Protective relative humidity. Values are means ± SE for 7 lean and 7 obese subjects at 34, 36 and 38°C and 7 lean and 5 obese subjects at 42°C. Protective RH, protective relative humidity for 95% of the population, 2 standard deviations below the mean ....102

Table B.1. Subjective responses to the physical activity enjoyment scale by day of heat acclimation. Values are means ± SE for 7 lean and 7 obese subjects .......................156

Table B.2. Urine variables by day of heat acclimation. Values are means ± SE for 7 lean and 7 obese subjects. \( U_{\text{vol}} \), urine volume; \( U_{\text{col}} \), urine color; \( U_{\text{sg}} \), urine specific gravity; \( U_{\text{osmol}} \), urine osmolality ............................................................................................................. 157

Table B.3. Subjective responses to the physical activity enjoyment scale by trial. Values are means ± SE for 7 lean and 7 obese subjects at 34, 36 and 38°C and 7 lean and 5 obese subjects at 42°C ..............................................................................................................158

Table B.4. Urine variables for the critical environmental limits study. Values are means ± SE for 7 lean and 7 obese subjects at 34, 36 and 38°C and 7 lean and 5 obese subjects at 42°C. \( U_{\text{vol}} \), urine volume; \( U_{\text{col}} \), urine color; \( U_{\text{sg}} \), urine specific gravity; \( U_{\text{osmol}} \), urine osmolality ................................................................................................................... 159
LIST OF ABBREVIATIONS

Air Velocity v
Amateur Athletic Union AAU
Blood Pressure BP
Body Core Temperature $T_c$
Body Surface Area $A_D$
Body Weight BW
Carbohydrate-Electrolyte Solution CES
Change in Mean Body Temperature $\Delta T_b$
Change in Time $\Delta t$
Correlation Coefficient r
Critical Water Vapor Pressure $P_{crit}$
Dehydration DEH
Dry Bulb Temperature $T_{db}$
Euhydration EUH
External Work W
Fractional Grade of the Treadmill $f_g$
Heart Rate HR
Heat Storage S
Maximal Evaporative Capacity of the Environment $E_{max}$
Maximal Oxygen Uptake $\dot{V}_{O_2max}$
Mean Arterial Pressure MAP
Mean Skin Temperature $\bar{T}_{sk}$
Metabolic Rate M
Net Metabolic Heat Production $M_{net}$
Oxygen Uptake $\dot{V}_{O_2}$
Placebo P
Radiative and Convective Dry Heat Exchange $R + C$
Radiative and Convective Heat Transfer Coefficient $h_{re+c}$
Ratings of Perceived Exertion RPE
Required Evaporation to Maintain Heat Balance $E_{req}$
Respiratory Exchange Ratio RER
Root Mean Square Deviation RMSD
Saturated Water Vapor Pressure of the Skin and Air Gradient $P_{s,sk} - P_a$
Skin Evaporative Capacity $E_{sk}$
Skin Temperature $T_{sk}$
Skin Temperature of the Chest $T_{chest}$
Skin Temperature of the Thigh \( T_{\text{thigh}} \)
Skin Temperature of the Triceps \( T_{\text{triceps}} \)
Skin Temperature of the Upper Back \( T_{\text{back}} \)
Skin Wettedness \( w \)
Temperature Gradient Between Ambient Air and Skin \( T_{\text{db}} - T_{\text{sk}} \)
Thermal Sensation \( T_{\text{TS}} \)
Walking Velocity \( v_w \)
Water Vapor Pressure \( P_a \)
Wet Bulb Temperature \( T_{\text{wb}} \)
Wet-Bulb Globe Temperature \( \text{WBGT} \)
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Chapter 1
INTRODUCTION

Background and Significance

In children, the salutary effects of regular physical activity include improved mental health (115), weight control (153), and a reduction in the risk for common chronic conditions such as cardiovascular disease (51; 119), hypertension (104), and type 2 diabetes (120; 150). As exercise is frequently prescribed as a main combatant of the pediatric obesity pandemic and as a greater number of children become more physically active, especially during the warm summer months, ensuring their physical well-being during every exercise session is imperative. Factors which could affect a child’s physical performance, subjective comfort and/or physical well-being during exercise in the heat include hydration status, degree of heat-acclimatization (induced in natural environment) / acclimation (induced over a shorter period of time, often in a laboratory setting), and severity of environmental conditions. However, there is a dearth of empirically-based information examining the impact of these factors on the physiological and subjective responses of children exercising in the heat.

Physiological Effects of Dehydration

Like adults, children become progressively dehydrated (DEH) when voluntary fluid intake is insufficient to match fluid lost as sweat (15; 27). Thermoregulation in a dehydrated child may be less efficient than in an adult. Children have a lower sweating rate per sweat gland, a lower cardiac output, smaller blood volume, generate more metabolic heat and have a greater
body surface area ($A_D$) to mass ratio which could result in greater relative fluid loss when compared to adults (49). Previous research in boys has suggested that for each 1% body weight (BW) loss a concomitant 0.28°C increase in body core temperature ($T_c$) is observed (15). DEH as little as 2% of initial BW results in an elevated heart rate (HR) (3) and $T_c$ (15) compared with euhydration (EUH) during exercise, suggesting that even low levels of DEH result in a greater physiological stress during exercise.

**Fluid Balance and Physical Performance**

Children are routinely encouraged to participate in team sports in order to reap the associated physical and psychological benefits. However, very little is known regarding the impact of DEH and/or carbohydrate intake on athletic performance in children, especially during the type of short-duration, high-intensity intermittent activity that characterizes many team sports. Boys 15- to 17-yrs of age who lost ~1% of initial BW while consuming a carbohydrate-electrolyte solution (CES) *ad libitum*, performed more sprints and spent more time running during a soccer game compared to a group who lost ~2% BW by ingesting no fluid (58). During a 40-min two-on-two full-court basketball game, compared to ingesting water, fluid restriction which eventually reached 2% of initial BW did not impair basketball shooting performance, anaerobic power, or measures of vertical jump height in 17-yr-old boys (63). Compared to rehydrating with water, fully replacing fluid losses with a 6% CES improved maximum power in high school football players (97). The impact of DEH and/or CES ingestion on sport specific performance during short-duration, high-intensity intermittent activity in children younger than 15 yrs of age is not known.
Heat-Acclimatization / Acclimation

While both children and adults are able to acclimate to exercise in the heat, children acclimate at a slower rate (64) and attain a level of acclimation that is somewhat lower (164) than adults. Only two studies (61; 62) have investigated the responses of obese / overweight vs. lean children to exercise in the heat, with both studies demonstrating no difference in heat tolerance (exercise time in the heat before a Tc of 39.4°C was reached) between groups. However, although all subjects in both studies underwent 3 exercise / heat-acclimation sessions prior to the heat tolerance trials, these data were not presented or discussed. Thus, neither the relative ability of obese vs. lean children to acclimate to exercise in the heat nor a comparison of their rate of acclimation has been investigated.

In adults, exposure to summer heat confers some degree of natural acclimatization. During both a passive heat stress and exercise in the heat, Tc and HR are lower and sweating is more profuse and dilute in summer compared to winter months (168). Due to this natural acclimatization, full artificially-induced heat-acclimation in a warm environment occurs more rapidly (46). A high degree of fitness also hastens the acclimation process (128). Children indigenous to tropical climates display high sweating rates, and a heat tolerance similar to adults during exercise in the heat (123; 124). However, for both obese and lean children residing in more temperate climates, the degree of natural acclimatization incurred during the summer months and its impact on subsequent acclimation-related changes when exposed to regular exercise / heat exposures are unknown.
Prescriptive Zone

Over a wide range of climatic conditions termed the “prescriptive zone”, (84; 85) $T_c$ is proportional to the work load (and therefore metabolic rate ($M$)) and independent of ambient conditions (110; 142). Within the prescriptive zone, $T_c$ can equilibrate through physiological adjustments. As climatic heat stress increases, combinations of ambient temperatures and water vapor pressures ($P_a$) above this zone force $T_c$ upward, due to an imbalance between heat gain and heat loss, resulting in uncompensable heat stress. While the critical environmental conditions that define the upper limit of the prescriptive zone for a given metabolic heat production have been determined for both heat-acclimated (21; 69; 70) and unacclimated (76) men and women, no study has defined these conditions for exercising children.

The approach used in the few studies investigating a child’s tolerance to exercise in the heat was to determine the time in a fixed environment in which a child was unable to continue exercising due to either subjective criterion (nausea, headache, etc) or measured physiological responses (rectal temperature > 39°C or > 90% of maximum HR) (41; 44; 61; 62; 164). Exercising obese / overweight vs. lean children display no difference in heat tolerance (exercise time in the heat before a $T_c$ of 39.4°C was reached) but a greater physiological strain as indexed by a higher $T_c$ and HR (61; 62). Review of this data collectively gives an indication of the environmental conditions which might reduce a child’s exercise performance. From this information, organizations have developed position stands providing specific recommendations for setting restraints on activities at differing levels of climatic heat stress for exercising children (4; 7; 24). However, each study employed an approximately 10° increase in climatic conditions among trials, thus the environmental limit for uncompensable heat stress, above which an imbalance between heat gain and heat loss forces $T_c$ upward, is difficult to determine. In
addition, it is unclear if obese children exercising in the heat should have a different set of guidelines to follow compared to lean children.

Summary

The three studies that comprise this dissertation were performed in order to: 1) determine the effect of 2% exercise-heat induced DEH and 6% CES EUH compared with placebo (P) EUH on basketball skill performance measures within a simulated game context in highly skilled young players; 2) determine the degree of natural acclimatization and artificially-induced acclimation-related changes during repeated exercise / heat bouts in 9- to 12-yr-old lean and obese boys during summer months; and 3) determine the critical environmental limits for exercising heat-acclimated 9- to 12-yr-old lean and obese boys.

Specific Aims and Hypotheses

Specific Aim 1: The purpose of the study “Two percent dehydration impairs and six percent carbohydrate drink improves boys basketball skills” was to determine the effect of 2% exercise-heat induced DEH and 6% CES EUH compared with P EUH on basketball skill performance measures within a simulated game context in highly skilled young players.

Hypothesis 1a: CES EUH will improve 12- to 15-yr-old boys’ basketball performance measures compared with P EUH.

Hypothesis 1b: 2% DEH will impair 12- to 15-yr-old boys’ basketball performance compared with P EUH.
Specific Aim 2: The purpose of the study “Responses of lean and obese boys to repeated summer exercise-heat bouts” was to determine the degree of initial natural acclimatization and subsequent artificially-induced acclimation-related changes during repeated exercise / heat bouts in 7 lean and 7 obese 9- to 12-yr-old boys during summer months.

Hypothesis 2a: Obese compared to lean 9- to 12-yr-old children will be less naturally acclimatized to the heat as shown by significantly higher baseline T<sub>c</sub>.

Hypothesis 2b: Obese compared to lean 9- to 12-yr-old children will display a significantly slower time course for the classic markers of acclimation (e.g., day to day decreases in exercise T<sub>c</sub> and HR, elevations in sweating rate) during repeated days of light-to-moderate intensity exercise in a warm, humid environment.

Specific Aim 3: The purpose of the study “Critical environmental limits for exercising heat-acclimated lean and obese boys” was to determine the critical environmental limits for uncompensable heat stress, above which an imbalance between heat gain and heat loss forces T<sub>c</sub> upward for exercising, heat-acclimated lean and obese 9- to 12-yr-old boys.

Hypothesis 3: During light-to-moderate intensity exercise in a warm environment, the critical environments for heat-acclimated obese vs. lean 9- to 12-yr-old children will be shifted downward on a psychrometric chart, toward a lower critical water vapor pressure (P<sub>crit</sub>). The P<sub>crit</sub> was identified by a continuous rise in T<sub>c</sub> and was defined as the critical ambient water vapor pressure above which thermal balance could not be maintained during exercise.
Chapter 2

REVIEW OF THE LITERATURE

Our understanding of an individual’s response to exercise is derived mostly from studies in adults. Investigations characterizing a child’s response to exercise are not as copious and as is noted repeatedly throughout the developmental exercise physiology literature, “children are not miniature adults”. While the response of a child to exercise is most often similar to that of an adult, it is the magnitude of that response variable that may be different for the child. Although progress has been made to try to understand a child’s response to exercise, numerous factors working either alone or in concert have impeded this progress, such as accounting for the growth and development of a child and its effect on a physiological response (and not all children grow at the same rate), and/or the ethical constraints and methodological limitations inherent to working with children. Moreover, when exercising in a hot / humid environment, children demonstrate different thermoregulatory responses compared to adults. Although the three studies that comprise this dissertation did not directly compare children and adults, it is germane in this review to first characterize an adult’s response to 1) exercise, 2) passive heat stress, and 3) an exercise plus heat stress to serve as a frame of reference to subsequently compare how children might differ from adults in these three areas. The subjects who participated in these studies were of different chronological ages and maturational stages. Thus comparing the “child-like” response to the “adult-like” response in these three areas is important to determine if the child’s physiological response is deficient which could potentially affect their physical performance, subjective comfort and/or physical well-being. In addition, heat-acclimatization /
acclimation and fluid balance, both which affect the thermoregulatory efficiency of a child exercising in the heat, will be discussed.

**Responses to Exercise in Adults**

During exercise, the cardiovascular system needs to meet the increased metabolic needs of the exercising muscles while at the same time defending blood pressure (BP). This is accomplished by both central and peripheral physiological adjustments. As illustrated by the Fick equation: oxygen uptake (\(\dot{V}O_2\)) = cardiac output x arterial-venous oxygen difference. Cardiac output can be described as HR x stroke volume and during exercise, increases in cardiac output are the result of increases in both HR and stroke volume (131). In untrained or moderately trained subjects, stroke volume plateaus at a workload of \(~40\%\) of maximal oxygen uptake (\(\dot{V}O_{2\text{max}}\)), and increases in cardiac output above this point are the result of increases in HR (129). Using atropine to block parasympathetic nervous system and propranolol to block the sympathetic nervous system, Robinson et al., (126) demonstrated that the initial increase in HR stems from withdrawal of vagal tone and that above 100 beats per minute, increases in HR are the result of increases in sympathetic nervous system outflow. There are four main determinants of stroke volume: 1) preload (end diastolic volume – or amount of blood returning to the heart), 2) afterload (BP), 3) HR and, 4) contractility (118). During exercise, increases in preload, mediated via mechanisms which increase venous return such as the respiratory and muscle pumps, result in more blood being emptied from the heart with each beat (Frank Starling mechanism) (103). In addition, increases in sympathetic nervous system outflow to the heart result in increase contractility which pumps more blood from the heart with each beat (131).
In order to meet the enhanced metabolic needs during exercise, the increase in cardiac output is directed toward skeletal muscle, while blood flow to compliant regions decreases (i.e. splanchnic and renal) (163). Increases in blood flow to working skeletal muscle result in an increase in the arterial-venous oxygen difference from ~6 ml oxygen / 100 ml blood to ~17 ml oxygen / 100 ml blood (118). At the beginning of exercise and during the first few minutes, there is an initial cutaneous vasoconstriction which subsequently diminishes and gives rise to active cutaneous vasodilation as T_c begins to rise (23).

There are three important mechanisms which coordinate the overall cardiovascular response to exercise: 1) central command, 2) baroreflexes, and 3) skeletal muscle chemoreflexes and mechanoreflexes (132). The central command hypothesis proposes that the initial signal to the cardiovascular system at the beginning of exercise comes from the central nervous system: the cerebral cortex signals the cardiovascular control centers in the pons and medulla to increase ventilation, HR and BP. Baroreflexes and skeletal muscle chemoreflexes and mechanoreflexes help to fine-tune this response. Evidence supporting the central command theory was provided by Krogh and Lindhard (78) who noted in their classic study that the rapid increase in HR and ventilation at the onset of exercise happened too quickly to be explained by either muscle chemoreflexes or increases sympathetic nervous system outflow, thus this increase must be central in origin. In a follow up study, the same authors (79) comparing electrical stimulation vs. voluntary exercise, showed a slower increase in HR in response to electrical stimulation, again suggesting a central origin for the increase in HR during voluntary exercise. Further evidence comes from the findings of Alam and Smirk (2) where a subject with one normally functioning leg and one leg without sensory feedback but intact muscle function perform leg exercise. They
showed a normal BP response to exercise in the leg without sensory feedback, supporting the idea of centrally generated signals.

Fine-tuning the cardiovascular response to exercise are baroreceptors, located in the heart and pulmonary vessels (low pressure cardiopulmonary baroreceptors) and aortic arch and carotid arteries (high pressure arterial baroreceptors). The arterial baroreceptors respond to increases / decreases in BP by altering HR, contractility and vascular resistance (132). For example, an increase in BP would be sensed by the arterial baroreceptors to signal the central nervous system to decrease HR and sympathetic nervous system activity to the heart and vasculature. During exercise, the arterial baroreflex is not turned off but rather is reset to a higher operating point (131). Evidence for this comes from exercising dogs with either intact or denervated baroreflexes (96). Denervated dogs demonstrate an immediate drop in BP in response to light exercise, whereas this drop in BP during heavier exercise recovered to resting levels. Presumably this is due to increased central command and / or exercise pressor reflex signals, thus demonstrating overlapping control mechanisms.

Skeletal muscle chemoreflexes and mechanoreflexes also help to fine-tune the cardiovascular response to exercise. Type III (more sensitive to stretch) and Type IV (more sensitive to chemical stimuli) afferents respond to stimuli by increasing HR, BP and contractility (132). Evidence for the muscle chemoreflex was provided by Alam and Smirk (1) who in adults, stopped the circulation to an exercising limb and demonstrated that BP remained elevated after exercise stopped (when there was no central command or muscle contractions) presumably due to metabolites being trapped and stimulating muscle chemoreflexes. In humans, electrically stimulated muscle contractions elicit an increase in HR (132) which provides evidence for the muscle mechanoreflex.
Responses to Exercise in Children

At rest, there is a progressive decline in resting cardiac output per kilogram as children grow (71). Compared to an adult at a measured \( \dot{V}o_2 \), a child’s cardiac output is significantly attenuated (159). No apparent gender differences exist in the cardiac output response to exercise in children (5), however this finding should be interpreted with caution since only a small number of studies have investigated sex differences, with the majority of studies using only boys or grouping boys and girls together for the data analysis. Studies are equivocal regarding if there are differences in maximal cardiac output between children and adults. Compared to adults, maximal cardiac output has been shown to be attenuated in children and to increase with age as a result of increases in stroke volume (53). But, when expressed per \( A_D \) (cardiac output / \( A_D \) = cardiac index), max cardiac index was not different between boys and men (137), while others have shown a lower max cardiac index in girls vs. boys (105). Through allometric analysis using \( A_D \), Rowland et al. (136) found no difference between girls and women in maximum cardiac output.

At rest, stroke volume increases as a child grows, presumably resulting from increases in heart size (80). Similar to adults, in response to graded exercise, stroke volume increases until \(~40\% \dot{V}o_{2\text{max}}\) and then plateaus as exercise intensity increases. This was demonstrated by Turley and Wilmore (158) who showed no significant increase in stroke volume above \(~40\% \dot{V}o_{2\text{max}}\) during graded exercise on either the bike or treadmill in boys and girls. Compared to adults, children have a lower stroke volume per kilogram in response to graded exercise, however if scaled to \( A_D \) (stroke index), these differences are smaller (159). Rowland (138) postulated that this lower stroke volume response to graded exercise could be the result of a decrease in sympathetic nervous system stimulation to the heart as demonstrated by attenuated
catecholamine levels in children vs. adults during exercise. In addition, the finding of a higher systemic vascular resistance during exercise (159) in children vs. adults, could contribute to this lower stroke volume. Boys have a higher stroke volume than girls when expressed per kilogram (5; 19) or when data are analyzed using multilevel modeling to control for body size and body fat during a 3 year longitudinal study (9). Maximal stroke volume appears not to be different in children compared to adults as demonstrated by Rowland et al., (136) who found no difference between girls and women in maximal stroke volume expressed relative to allometrically-adjusted AD.

As a child grows, since resting stroke volume increases, then the decline in resting cardiac output must be explained by a decline in resting HR with age. From age 4 to 20 years, resting supine HR decreases from 85 to 60 beats per minute (88). The mechanism for this decrease is unknown; however it could possibly be related to changes in SA node depolarization. Marcus et al. (89) using atropine to block the parasympathetic nervous system and propranolol to block sympathetic nervous system demonstrated higher intrinsic SA node firing rates in children vs. adults. It is unclear if the increases in HR in response to graded exercise (the 100 bpm threshold for sympathetic nervous system stimulation) demonstrated in adults is similar in children. Sady et al. (140; 141) in a series of studies comparing the HR response between prepubertal boys and adult men during short bouts of cycle exercise at intensities above and below \( V_{\text{O2max}} \) found that children display a faster increase in HR at the higher intensities, with no differences between groups at the lower intensities. Thus, at the beginning of exercise, the HR response is different between children and adults. Children have a higher steady-state HR at a given absolute (159) and relative workload (172). Is it assumed that this higher HR tries to compensate for the lower stroke volume, however this does not occur as demonstrated by the
lower cardiac output in children vs. adults during graded exercise at a given $\dot{V}o_2$ (159). At a given exercise intensity, boys have a lower HR than girls (19). Maximal HR during both weight-bearing and non-weight bearing exercise is constant as a child grows. Over the span of 8 years, maximum HR did not differ by more than 3 beats per minute (average = 196 beats per minute) during treadmill running in boys (12). This finding implies that the target HR formula (220-age) used in adults is not applicable for children, since maximal HR is not dependent on age during the growing years.

In order to obtain an $\dot{V}o_2$ similar to an adult, a child with a lower cardiac output must have a higher arterial-venous oxygen difference (19; 159). The mechanism behind this is unclear but could be related to higher muscles blood flows in children, as demonstrated by Koch (77) using the $^{133}$Xe-clearance technique. However, other studies have shown either no difference (161) or a higher arterial-venous oxygen difference in adults vs. children (137).

It is unclear if there are differences in the BP response to exercise between children and adults. In children, systolic BP increases as exercise intensity increases (47; 158). The diastolic BP response to exercise in children is equivocal most likely due to the measurement error associated with BP measures during exercise (155). However, it does appear that similar to adults, BP is the variable which is defended during exercise.

There is very limited data addressing the mechanisms which coordinate the overall cardiovascular response to exercise in children. In a series of studies, Turley investigated the muscle chemoreflex in boys vs. girls (156) and children vs. adults (157) using the same protocol in both studies. Subjects performed a static hand grip at 30% of maximal voluntary contraction for 3-min, followed by 4-min where blood flow was stopped, and then 6-min of recovery. Boys and girls displayed a similar increase in HR and BP in response to static hand grip exercise,
followed by a similar drop in HR back to resting levels, while BP remained elevated above resting level during post-exercise ischemia in both groups. This suggests that the HR response stems from central command while the post-exercise ischemic BP response stems from muscle chemoreceptors. Once circulation was restored, the trapped metabolites which were washed away into the circulation, stimulated arterial chemoreceptors and during the recovery period, the BP response was similar in boys and girls. In children vs. adults using the same protocol, both groups demonstrated increases in HR and BP in response to static hand grip exercise. During post-exercise occlusion, in both groups, HR returned to resting levels while BP remained elevated above resting levels. Upon restoring blood flow, the metabolites which had been entrapped were washed into the systemic circulation, stimulating the arterial chemoreflex. In children, this resulted in BP remaining elevated above resting levels whereas in adults it returned to baseline. This suggests that children may have a more active arterial chemoreflex compared to adults. Also, these findings suggest that the muscle chemoreflex responds in a similar manner in children and adults.

**Responses to Thermal Stress in Adults**

Under thermoneutral conditions, skin blood flow is controlled by the sympathetic adrenergic vasoconstrictor system (release of norepinephrine binding to alpha-receptors). In response to thermal stress, initially skin blood flow increases as a result of withdrawal of vasoconstrictor tone (which approximately doubles skin blood flow) and upon reaching a threshold, sweating will begin and further increases in skin blood flow occur due to sympathetic cholinergic active vasodilation (release of Ach causes sweating response and co-release of unknown neurotransmitter results in cutaneous vasodilation) (73). Activation of cutaneous
vasodilation can increase skin blood flow up to ~8 L/min (129). However, there is competition between the two reflexes and in response to BP challenges (excessive cutaneous vasodilation), the baroreflexes will sense the drop in BP, and will reduce skin blood flow in order to defend BP. This was shown by Johnson et al., (67) who using whole body heating interspersed with bouts of low body negative pressure, raised skin temperature (Tsk) to increase forearm skin blood flow and Tc. When low body negative pressure was applied, cutaneous vasoconstriction occurred while mean arterial pressure (MAP) remained unchanged.

In order to meet the demands of cutaneous vasodilation, cardiac output increases, and all of this blood flow is directed to the skin, while blood flow decreases to other vascular beds (splanchnic, renal and skeletal muscle (130)). The overall cardiovascular response to thermal stress can be illustrated via studies conducted by Rowell (129; 133). Water perfused suits “clamped” Tsk at 40°C in an effort to reverse the Tc-Tsk gradient. In response to this thermal stress, cardiac output, stroke volume, and HR rose, and right atrial pressure, splanchnic, renal and muscle blood flow fell, all while arterial BP was well maintained.

Responses to Thermal Stress in Children

In general, the thermoregulatory responses of a child to a heat stress are similar to those of an adult. However, there are some differences which will be discussed below. Heat can be gained or lost to the environment via conduction, convection, radiation and evaporation and the rate of heat gain or loss via any of these mechanisms depends on the AD. Children have a greater AD / mass ratio, and theoretically should gain heat faster compared to adults in hot climates. Leppaluoto (83) in a review of studies exposing children and adults to sauna baths found that in adults Tc increased 0.9°C after 30-min at 80°C whereas less severe conditions increased
children’s $T_c$ by 1.5°C after only 10-min. Jokinen et al., (68) compared the thermoregulatory responses of infants, children and adults during a 70°C sauna exposure. Rectal temperature rose to a higher value (similar to the numbers reported in the Leppaluoto review above). HR increased and stroke volume decreased faster in the children vs. adults. Cardiac output increased in both children and adults, except for very young children and BP was well maintained during the sauna exposure. However, right after the exposure, two younger children collapsed due to a decrease in both systolic and diastolic BP.

In response to a heat stress, children have a lower sweating rate per BSA than adults as demonstrated by Shibasaki et al. (147) who passively heated prepubertal boys and adult men by placing their legs in a hot water bath. This lower sweating rate could diminish the ability for evaporative heat loss.

Martin et al., (93) measured skin blood flow at thermoneutral and hot (42°C) $T_{sk}$ while sitting at rest in children and adults. There were no differences between groups at a thermoneutral $T_{sk}$; however, while $T_{sk}$ was clamped at 42°C, maximal skin blood flow (forearm vascular conductance) was higher in the children vs. adults. The authors hypothesized that the decline in forearm vascular conductance with age might reflect structural changes in skin blood vessels.

**Responses to Exercise Plus Heat Stress in Adults**

Exercising in a hot environment is a major challenge to the cardiovascular system due to the competition for blood flow between skin to dissipate heat and muscle to support the enhanced metabolic needs. Since during an exercise plus heat stress, providing unlimited blood flow to each vascular bed could easily outstrip the maximal cardiac output, the cardiovascular
system must set priorities and impose restrictions. The priority is to defend BP, and the restrictions which help to accommodate this priority are (via sympathetic nervous system and thermoreceptor stimulation) to reduce blood flow first to compliant vasculatures (i.e. splanchnic and renal) and if needed, to skin and even muscle (54) at maximum exercise during heat stress (132). Kenney et al., (75) by blocking $\alpha_1$-receptors showed that the reduction in skin blood flow during exercise in the heat is not the result of increasing vasoconstrictor activity, which suggests that it is via reducing active cutaneous vasodilation. This displacement of blood volume from compliant vasculatures helps to maintain BP, thus it appears as if BP and not $T_c$ is the regulated variable (131).

Activation of cutaneous vasodilation can increase skin blood flow up to ~8 L/min (129) and this large increase in skin blood flow results in a reduction in the return of blood back to the heart (cardiac filling) since the cutaneous vasculature is a compliant circulation. In addition, sweating rate increases and if sustained, can decrease the overall blood volume which also contributes to a reduction in the flow of blood back to the heart. In response to a reduced cardiac filling, contractility of the heart increases (increase in sympathetic nervous system stimulation) to try to prevent a fall in stroke volume. The cardiovascular response to exercising in a hot environment can be illustrated by the findings of Rowell (134) who had sedentary unacclimated men perform 15-min bouts of exercise at four intensities ranging from ~45 to ~ 85% $\dot{V}O_{2\text{max}}$ in a neutral and hot environment. Subjects stayed hydrated via saline injections. At the two lower workloads, cardiac output responded in a similar manner in both hot and neutral conditions. This occurred because HR increased in order to compensate for the decrease in stroke volume in the hot vs. neutral environment. At the two higher workloads, cardiac output was attenuated in the heat due to the inability of HR to increase further (had achieved maximum HR) coupled with
further reductions in stroke volume. Throughout all intensities in the hot vs. neutral environment, BP was maintained even though central blood volume was reduced.

**Responses to Exercise Plus Heat Stress in Children**

Theoretically, compared to adults exercising in a hot and/or humid environment, children have differing geometric and physiological characteristics that could affect their thermoregulatory efficiency. Due to their greater $A_D / \text{mass ratio}$, children rely more on convection and radiation and less on evaporation compared to adults as a means of heat exchange during exercise in thermoneutral (37) and hot (25; 40) environments. Depending on the environment (high humidity vs. high heat) this could affect their thermoregulatory efficiency. Per kilogram, children produce more metabolic heat which could subject a child’s thermoregulatory system to greater strain (10). During exercise in a hot environment, compared to men, boys have a lower sweating rate per $A_D$ (66) which could diminish the capacity for evaporative heat loss, while there appears to be no differences between girls and women (44). As the total number of sweat glands is set by age 2 (81), this attenuated sweating rate appears to be the result of a lower output per gland, in spite of the finding that children have a higher population density of heat-activated sweat glands (148). The explanation for a lower output per gland in children is elusive; however it could be related to the smaller size of a child’s sweat gland (82).

Regarding cardiac output, in a thermoneutral environment, compared to an adult at a measured $\dot{V}O_2$, a child’s cardiac output is significantly attenuated (159). In theory this could reduce the transfer of heat from the core to the periphery via blood flow while a child exercises in a hot environment. However, very few studies have compared the cardiovascular response to
exercise in a hot environment between children and adults to see if this theory has merit. The often cited study of Drinkwater et al., (44) had unacclimated prepubertal girls and women matched for $\dot{V}O_2$ walk for 2 50-min bouts on a treadmill at 30% $\dot{V}O_{2\text{max}}$ in three environments ($28^\circ$C, $35^\circ$C (hot humid) and $48^\circ$C (hot dry)). Fluid was not replaced during the exercise bouts. All subjects completed the exercise bout at $28^\circ$C. At $35^\circ$C and $48^\circ$C, time to exhaustion was decreased for the girls vs. women. The $T_c$ of the girls vs. women were higher at virtually all time points during both exercise bouts at $28^\circ$C and $35^\circ$C. At $48^\circ$C, this gap was reduced. During both exercise bouts at $28^\circ$C, $35^\circ$C and $48^\circ$C, the girls had a lower stroke index compensated for by a higher HR, since there were no statistically significant differences between groups in cardiac index. Also there were no differences in forearm blood flow or mean skin temperature ($T_{sk}$) between groups. The authors concluded that the reduced tolerance time of the girls vs. women was due to cardiovascular instability as demonstrated by the higher HRs and not impaired thermoregulatory ability. However, this conclusion is questionable since there were no differences between groups in cardiac index. Rivera-Brown et al. (124) had active, heat-acclimatized prepubertal girls and women matched for $\dot{V}O_2$ cycle at 60% $\dot{V}O_{2\text{max}}$ until fatigue outdoors (~$33^\circ$C) in direct sunlight. Subjects were rehydrated with a sports drink. There were no differences in sweating rate, increase in $T_c$, exercise time, or heat storage between groups. During exercise in the heat and at exhaustion, no impairment in cardiovascular function in either group was evident as demonstrated by similar HR, stroke indexes, and cardiac indexes. Thus, active heat-acclimatized girls who stay euhydrated are able to tolerate exercise in the heat as well as women of similar description. Although not a comparison between children and adults, a recent study by Rowland et al., (135) had active, unacclimated prepubertal boys cycle at 65% $\dot{V}O_{2\text{max}}$ until fatigue at $20^\circ$C and $31^\circ$C. Drinking of water was ad libitum with DEH levels
reaching <1% during exercise. Results suggest that cardiovascular insufficiency is not the limiting factor to explain the reduced exercise tolerance during exercise in the heat as stroke volume remained constant while HR and cardiac output rose throughout exercise. BP was well maintained in both conditions. The rate of rise in $T_c$ was faster during the exercise plus heat stress trial. Thus, the authors concluded that the increase in $T_c$ rather than cardiovascular insufficiency was the critical factor which limits a child’s exercise performance in a hot environment.

Few studies have investigated the skin blood flow response both during and after exercise in children. Shibasaki et al., (148) showed that compared to men, the cutaneous vascular conductance was higher on the back and chest but not forearm in boys during exercise in the heat. However, the authors used laser doppler flowmetry during exercise and this could cause measurement error due to the method being motion sensitive and in addition to sweat interference. Falk et al., (50) found higher forearm blood flows after exercise in the heat in pre-pubertal vs. post-pubertal boys.

Taken together, the implication based upon these differing characteristics is that, compared to adults during exercise, children are less efficient thermoregulators which puts them at increased risk for heat-related illnesses. In spite of this theoretical reasoning, evidence to support this statement is contradictory; while some studies support this statement (15; 43; 44; 61; 164), others oppose (36; 37; 40-42; 59). One variable that may help to explain the discrepancy among studies is the specific ambient conditions in which the children exercised. In some warm climates, children are able to sustain exercise and thermoregulate as effectively as adults, whereas in very hot environments (air-to-skin gradient of 10°C or more), a child’s exercise tolerance and thus, thermoregulatory ability may be attenuated (14). However, not all studies
support this notion. Meyer et al. (99) found no difference in the increase in $T_c$ from rest to the end of the session between prepubescent, pubescent and young adult males and females during 2 20-min cycle bouts at 50% $\dot{V}O_2peak$ at 42°C, 18% relative humidity. A recent study by Inbar et al., (66) found that while exercising in hot, dry conditions, prepubertal boys had the lowest heat storage and thus were the most efficient thermoregulators compared to young and elderly adults.

**Heat-Acclimatization / Acclimation**

Heat-acclimatization (induced in a natural environment) and acclimation (induced over a shorter period of time, often in a laboratory setting) result from repeated heat exposures which sufficiently increase $T_c$, and $T_{sk}$, and stimulate abundant sweating (168). In response, the body adapts to these repeated heat exposures through numerous physiological adjustments such as: 1) a reduction in the day-to-day $T_c$, HR and $T_{sk}$, 2) increase in sweating rate, 3) earlier onset of sweating, 4) more dilute sweat, and 5) increase in plasma volume (144). In addition, decreases in baseline $T_c$ have been observed following humid heat-acclimation (28). The induction of heat-acclimation during exercise is specific to the duration of exposure, environmental conditions, and intensity of exercise and can be attained in adults in 5-10 days through exercise / heat exposures lasting 1- to 2-hrs each day (144). While both children and adults are able to acclimate to exercise in the heat, children acclimate at a slower rate (64) and attain a level of acclimation that is somewhat lower (164) than adults.

During exercise in a hot and humid outdoor environment, fit vs. sedentary children who are born and raised in a tropical climate display very high sweating rates (123; 125). Although the American Academy of Pediatric guidelines (4) state that children should not perform physical activity if the wet-bulb globe temperature (WBGT) is greater than 29°C, heat-
acclimatized 11- to 14-yr old girl athletes are able to tolerate exercise in conditions of high heat and humidity (WBGT = 31.9 ± 1.5°C) (32). Compared to women, girls of similar aerobic capacity and level of heat-acclimatization display a stable HR, stroke index and cardiac index while cycling at 60% \( \dot{V}o_{2\text{max}} \) until fatigue in a hot and humid environment (web-bulb globe temperature = 29.9 ± 0.2°C). Subjects imbibed a sports drink to prevent DEH. This suggests that heat-acclimatized euhydrated girls are just as able to tolerate exercise in the heat as adult women of similar description (124).

**Fluid Balance**

Progressive DEH, resulting from an imbalance between *ad libitum* fluid intake and fluid loss as sweat, is common during exercise, with children routinely losing 1-2% (15; 98) and adults losing up to 4% (57) of their initial BW. In collegiate tennis players, Bergeron et al. (22) found BW deficits of 2-3% during match play. Walker et al. (165) reported that 12-yr-old children were not only chronically dehydrated throughout the course of a 4-day summer soccer camp in Pennsylvania, approximately half of the children showed up to the camp already dehydrated by 1-2%. During a kids’ triathlon race in Costa Rica, Wilk et al. (169) found that 50% of boys and 48% of girls between 8 and 13 yrs old lost 2-3% BW without adverse health consequences. One in three boys between 14 and 17 yrs old lost 2% BW, and 7% exceeded 3% DEH. Importantly, all of these events provided cold palatable fluids and allowed and encouraged *ad libitum* drinking! These studies support the statement that DEH levels of 2-4% are common in children and adolescents engaging in sports and / or recreational activity.

It has been suggested that thermoregulation in a dehydrated child may be less efficient than in an adult. Previous research comparing results in boys (15) to a study in adults (16),
showed that for each 1% BW loss the increase in $T_c$ in adults was 0.15°C whereas in boys was 0.28°C. However, there are numerous problems with this comparison such as: 1) different work/rest cycles – the adults rested for an additional 10-20 min; 2) different intensities – the children worked at 45% $\dot{V}O_{2max}$ (relative) whereas the adults worked at 4.8 km/h (absolute); 3) different exercise modalities – the children exercised on bike and the adults on exercised on a treadmill, and; 4) both the children and the adults were partially acclimatized (3 days) but since children acclimate at a slower rate (64) it is unclear how this could have affected outcome. The authors acknowledge in the discussion that the “methods were different” between the two studies (15). However due to the number and magnitude of these differences, it is questionable if the comparison was appropriate and if any meaningful conclusions can be drawn.

In adults, exercise-induced DEH has been shown to impaired athletic (34) as well as cognitive (55) performance during both prolonged continuous aerobic activity such as running (143) and cycling (52) and during short-duration, high-intensity, intermittent activity such as rowing (29) and soccer (95). Very few studies have examined the impact of DEH-associated impairments in performance in children. Meyer et al. (102) found no difference in cycle time to exhaustion among trials consisting of ad libitum consumption of water which resulted in mild DEH and three CESs which differed in the sodium content in 11 yr old boys and girls. Concerning high-intensity intermittent exercise performance in adolescents, Guerra et al. (58) showed that boys 15- to 17-yrs of age who lost ~1% of initial BW while consuming a CES ad libitum, performed more sprints and spent more time running during a soccer game compared to a group who lost ~2% BW by ingesting no fluid. During a 40-min two-on-two full-court basketball game, compared to ingesting water, fluid restriction which eventually reached 2% of initial BW did not impair basketball shooting performance, anaerobic power, or measures of
vertical jump height in 17-yr-old boys (63). In adults, compared to rehydrating with water, replacing fluid losses with a 6% CES improves intermittent, high-intensity athletic performance (38; 109; 160). In children, fully replacing fluid losses with a 6% CES improved maximum power in high school football players compared to rehydrating with water alone (97). The impact of DEH and/or CES ingestion on sport specific performance during short-duration, high-intensity, intermittent activity in children younger than 15 years of age is not known.

Since DEH has been shown to impair performance, and since compared to EUH during exercise, even low levels of DEH result in a greater physiological strain as indexed by higher HR (3) and Tc (15), it is logical that studies would examine both perceptual and physiological factors which might enhance drinking during exercise. In adults, beverage characteristics such as fluid flavor, temperature and color affect the palatability and ultimately the desire to drink (35). In 9- to 12-yr-old boys, compared to water, flavoring a beverage attenuates the DEH incurred during intermittent cycle exercise in the heat, whereas adding flavor plus 6% carbohydrates and 18 mmol/l NaCl prevents DEH altogether (170). Subsequent research bolstered this finding of a CES to prevent DEH. During repeated bouts of exercise in the heat over a 2-week period, ad libitum consumption of a grape-flavored CES consistently prevented DEH in 10- to 12-yr old boys (171). In trained heat-acclimatized trained boys exercising in a tropical climate, compared to unflavored water, a flavored CES prevented DEH (123). Thus, in summary it appears that to enhance drinking in the pediatric population, beverages should be flavored and contain NaCl (~18-20 mmol/l) and simple carbohydrates (~6-7%).
Chapter 3

TWO PERCENT DEHYDRATION IMPAIRS AND SIX PERCENT CARBOHYDRATE DRINK IMPROVES BOYS BASKETBALL SKILLS

Introduction

Athletes become progressively DEH when voluntary fluid intake is insufficient to match fluid lost as sweat. In youth team sports, levels of DEH of 2-3% or higher have commonly been reported. During a basketball game, 16- to 18-yr-old boys lost between 1 and 3% of initial BW (27). During 4-day summer camps, more than half of 14- to 16-yr-old boys football (33) and 10- to 14-yr-old boys soccer (39) players were significantly dehydrated (urine specific gravity ≥ 1.025) at the beginning and again at the end of each day’s session. In individual competition, Wilk et al. (169) found that during a triathlon race in Costa Rica, 50% of boys and 48% of girls ages 8 and 13 yr old lost 2-3% BW. One in three boys aged 14 and 17 yr old lost 2% BW, and 7% exceeded 3% DEH.

DEH has been suggested to impair athletic performance during short-duration, high-intensity, intermittent activity in adults. Compared to EUH with water, international-class rowers who lost ~2.5% of their initial BW took, on average, approximately 22 seconds longer to complete a maximal rowing test (29), loss of 2% BW impaired semi-professional soccer player’s skill performance by 5% (95), and DEH as low as 1.5% of initial BW resulted in a deterioration in intermittent sprinting performance (94). Whereas a few studies have examined the impact of DEH on intermittent exercise performance in adolescents (15; 100; 101), very few studies have evaluated the type of high-intensity intermittent exercise that characterizes many team sports. Moreover, the effect of carbohydrate intake has not been elucidated. During a soccer game, 15-
to 17-yr-old boys who lost approximately 1% BW while consuming a CES *ad libitum*,
performed more sprints and spent more time running compared to a group who lost
approximately 2% BW by ingesting no fluid (58). Studies have shown that replacing fluid loss
with a 6% CES improves intermittent, high-intensity athletic performance in adults compared to
rehydrating with water (38; 109; 160). But, again, very few studies have evaluated high-
intensity intermittent exercise in adolescent athletes. In high school football players, fully
replacing fluid loss with a 6% CES improved maximum power compared to rehydrating with
water alone (97). Many studies in adults have used team-sport athletes, but often the
performance measures of choice have neither mimicked game-type performance or have been
sport-specific (11; 106; 108; 109; 167). Studies investigating sport-specific performance in
adolescent athletes are sparse.

Basketball is a sport characterized by intermittent bouts of high-intensity exercise. In 17-
yr-old male basketball players, Hoffman et al. (63) found no difference between the water
ingestion and fluid restriction trials, eventually reaching 2% of initial BW over the course of a
40-min two-on-two full-court basketball game in measures of vertical jump height, anaerobic
power, or basketball shooting performance. However, the impact of DEH and/or CES ingestion
on basketball skill performance in boys younger than 17 yr of age is not known. Therefore, the
purpose of the present study was to determine the effect of 2% exercise heat-induced DEH and
6% CES EUH compared to P EUH on basketball skill performance measures within a simulated
game context in highly skilled young players.
Methods

Subjects

Fifteen male basketball players between 12 and 15 yrs of age volunteered to participate in this study. Each subject and his parent / guardian were advised of the experimental procedures and associated risks before verbal assent was given by the child and a written informed consent was provided by the parent / guardian. This study was approved by the institutional review board of The Pennsylvania State University. All subjects were healthy, fit, normotensive, nonobese, highly skilled basketball players who were not taking any medications. Each was a first-team member of either their school or district Amateur Athletic Union (AAU) team or both in the central Pennsylvania region. Preliminary screening included blood analysis (CHEM-24; (154)), a resting 12-lead electrocardiogram, skinfold measurement to determine adiposity, maximal vertical jump measurement (Vertec), a physical exam by a physician and a submaximal graded exercise test on a treadmill. \( \dot{V}O_{2\text{max}} \) was determined graphically by linear extrapolation. Subjects were familiarized with all testing procedures and viewed a video of all basketball drills to be performed in subsequent testing sessions. Subject characteristics are presented in Table 3.1.

Experimental Design

Each subject completed three double-blinded trials scheduled at least 1 wk apart in random order: 1) 2% DEH by limiting fluid intake; 2) EUH with a commercially available CES (6% carbohydrate and 18.0 mmol·L\(^{-1}\) Na); and 3) EUH with a flavored water P (0% carbohydrate and 18.0 mmol·L\(^{-1}\) Na). The fluid restriction (DEH) or drink treatment (EUH) was continued throughout the entire protocol (chamber exercise, recovery and basketball drills; see below) to
maintain the imposed level of DEH or EUH. Subjects were encouraged to stay well hydrated the
day before each trial. A minimum of 8 h before each test day, subjects swallowed an ingestible
temperature sensor (CorTemp, HQ Inc, Palmetto, FL) for the measurement of $T_c$. The sensor is a
single-use, pill-shaped electronic device that contains a telemetry system, a microbattery, and a
quartz crystal whose frequency of vibration is linearly related to temperature. Each temperature
sensor was calibrated by the manufacturer, which provides a serial number that is programmed
into a handheld recorder (CT2000) ensuring an accuracy of 0.1°C. Our lab has extensive pilot
data utilizing a similar protocol mimicking the stop-and-go nature of a basketball game, which
shows that the ingestible temperature sensor pills are an accurate reflection of rectal temperature
(Concordance Correlation Coefficient = 0.87). In addition, each pill was used with in 6 months
from the date it was shipped by the manufacturer.

**Euhydration / Dehydration Protocol**

Subjects reported to the laboratory on the morning of the test day after an overnight fast.
After providing a urine sample, the subject was instrumented with a Polar® HR monitor, weighed
(Seca 770, accuracy ± 50 g) wearing only shorts (all subsequent weights were taken wearing
shorts only), given 5 mL of water per kilogram BW to drink, and fed a standardized low-
carbohydrate breakfast (275 kcal total: 25g (36%) carbohydrate, 8g (25%) fat, and 28g (39%)
protein). An hour after breakfast and after providing a second urine sample, the subject was
reweighed and entered an environmental chamber set at 35°C, 20% relative humidity. After a
10-min baseline period, the subject completed 2 h of 15-min exercise bouts at 50% $\dot{V}O_{2\text{max}}$, with
5-min rest periods between bouts. Exercise bouts alternated between a treadmill (Precor USA
C962) and cycle ergometer (Monark Ergomedic 818E). The criterion for stopping exercise in
the heat was $T_c \geq 39.0^\circ\text{C}$. However, no subject exceeded this threshold. Change in BW was used to determine hydration status. During rest periods, subjects were weighed and either given fluid to maintain BW by replacing all water lost through sweat (EUH trials) or no fluid (2% DEH trial), depending on the trial. During the DEH trial, if the subject’s weight fell slightly below the calculated 2% of initial BW, he ingested distilled water in order to maintain the desired 2% DEH weight.

**Recovery Period**

Upon completion of the 2-h interval exercise protocol, the subject exited the chamber and provided a urine sample, then sat in a thermoneutral environment for 1-h in order to allow $T_c$ to return to baseline temperature. After recovery, the subject provided another urine sample. A schematic of the study design is diagrammed in Figure 3.1.

**Basketball Protocol**

In consultation with coaches from NCAA Division I, II, III and AAU basketball programs, an orchestrated sequence of continuous basketball drills, which the subject performed 15-min after the end of the 1-h recovery, was designed to simulate a basketball game with four 12-min quarters and a 10-min halftime rest. This comprehensive set of drills addressed basketball-specific skills inherent to the game. A schematic of the basketball drills protocol is presented in Figure 3.2. The drink treatment was continued to maintain the imposed level of DEH or EUH. The first quarter consisted of six drills: 1) layup shooting: start at the elbow, dribble in, and shoot a layup, then get own rebound, dribble to opposite elbow, dribble in, and shoot a layup and repeat (number made in 1 min); 2) suicide sprints: start at baseline, sprint to
foul line, sprint back to baseline, sprint to half court, sprint back to baseline, sprint to opposite foul line, sprint back to baseline, sprint to opposite end line, sprint back to baseline (time to completion); 3) 10 vertical jumps: 70% of maximum vertical jump was measured and subject was asked to repeatedly touch that mark above him 10 times as quickly as possible (time to completion); 4) zigzags: defensive slide to each cone set in a zigzag pattern from baseline to baseline on half of the basketball court (time to completion); 5) around the world shooting: continuous 15-foot shooting from seven spots (number made in 1 min); 6) full-court combination: defensive drill combining lateral and front-to-back movement, start at corner, sprint forward to half court, defensive slides across midline, sprint forward to opposite corner, defensive slides across opposite baseline, backpedal to midline, defensive slides across midline, backpedal to baseline, defensive slides across baseline (time to completion). The second quarter consisted of six drills: 7) 3-point shooting: continuous 3-point shooting from seven spots (number made in 1 min); 8) 10 court widths sprints (time to completion); 9) maximum vertical jump: subject allowed one step and then must jump off of two feet (best height of three attempts); 10) 20 lane slides: defensive slides across width of key (time to completion); 11) free-throw shooting: (number made in ten attempts); 12) key combination: defensive drill combining lateral and front-to-back movement, start on baseline at corner of key, sprint forward along line to top corner of key, diagonal defensive slide to opposite corner of key on baseline, sprint forward along line to top key corner, diagonal defensive slide to opposite corner of key (time to complete five).

After obtaining a urine sample at halftime, the drills performed in the third quarter were the same as the first quarter drills, and the fourth quarter drills were the same as the second quarter. At the end of the basketball protocol, the subject provided the last urine sample.
Performance measures were single and combined long-range shooting percentage (3-point, 15-foot, and free-throw shots), single short-range shooting percentage (layups), single maximum vertical jump, single repetitive vertical jumps, and single, average, and total times for sprints (suicides and court widths), lateral movement (zigzag and lane slides), and defensive (full-court combination and key combination) drills. Because each drill was performed once in two separate quarters, each individual performance measure was the average of the two scores. For the drills in which the performance measure was time to completion (sprints, lateral movement, and defensive drills), the average times were the average of the single performance scores, and the total times were the sum of the single performance scores.

**Dehydration Trial**

After breakfast and right after the subject voided, but before the DEH protocol, a baseline BW was obtained. A 2% DEH weight was established by calculating a 2% decrease from this baseline BW. After exercise in the chamber, the subject voided again. Urine production at this time was minimal. During recovery, BW was recorded every 15 min during which the subjects 2% DEH weight was fine-tuned. After recovery and before the basketball drills, the subject voided, again with minimal urine production. Thus, the subject lost approximately 2% of his initial BW.

**Measurements**

HR, BP measured by brachial auscultation (sphygmomanometry), T_c, and ratings of perceived exertion (RPE; Borg scale; (26)), were measured at 20-min intervals during the chamber exposure. During rest periods in the chamber, BW and volume of fluid consumed
(when required) were measured. During recovery, BW, Tc, HR and BP were measured at 15-min intervals. During the basketball protocol, Tc, HR, RPE, volume of fluid consumed and BW were measured at halftime and at the end of the protocol.

**Subjective Ratings**

A survey was administered to the subject at the end of the chamber session, at halftime, and at the end of the basketball protocol. Subjective feelings of physical and psychological well-being were assessed by visual analog rating scales. Subjects rated feelings of lightheadedness (not lightheaded to very lightheaded), being out of breath (not out of breath / winded to very out of breath / winded), hotness (not feeling hot / overheated to feeling very hot / overheated), aches (no side-stitch / ache to severe side-stitch / ache), muscle cramping (no muscle cramping to severe muscle cramping), total body fatigue (no total body fatigue to severe total body fatigue), upper body fatigue (no upper body fatigue to severe upper body fatigue), and leg fatigue (no leg fatigue to severe leg fatigue). The subject answered these questions by placing a mark on a 100-point scale between the extreme answers at opposite ends of the line.

**Urine Analyses**

Urine volume was measured and urine color was determined by holding each specimen container next to a validated color scale (8) in a well-lit room. The eight-color scale ranges from 1 (very pale yellow) to 8 (brownish green). Urine osmolality (freezing point depression, Advanced DigiMatic Osmometer Model 3D2), and specific gravity (Refractometer, Atago A300CL) were determined in triplicate.
Calculations

MAP was calculated as MAP = (1/3) pulse pressure + diastolic BP. Total body sweat loss was calculated from the net change in BW corrected for fluid consumption and urine excreted.

Statistical Analyses

The performance, physiological, and subjective data were analyzed with a linear mixed model by using SAS PROC MIXED. The covariance structure was chosen by the Akaike Information Criterion (AIC). Treatment and time were treated as fixed effects, and subjects were treated as random effects. For the performance and subjective data, the $P$ values were adjusted for the multiple comparisons between the treatment groups using a Tukey post hoc test. For the physiological data measured over different time points, each $P$ value was adjusted for the multiple comparisons between the treatment groups using a Bonferroni post hoc test. The significance level for all statistical tests was set at alpha = 0.05. All data are presented as means ± SD.

The two distinct hypotheses tested were 1) CES EUH will improve 12- to 15-yr-old boys’ basketball performance measures compared with P EUH, and 2) 2% DEH will impair 12- to 15-yr-old boys’ basketball performance compared to P EUH. To present the comparison of skill performance results for CES vs. P EUH and DEH vs. P EUH trials, data from the P EUH trial were subtracted from CES and DEH trial (Figures 3.4, 3.5, and 3.6) because the data are paired data from the same subject. Taking the difference from P EUH better reflects each hypothesis directly, removes the subject effect, and provides an effective comparison of the two treatments.
Results

Physiological and RPE variables for baseline, at the end of the 2-h chamber exposure, recovery, quarter 2, and quarter 4 are presented in Table 3.2. At the end of the chamber protocol in the DEH trials, HR ($P < 0.001$ each), $T_c$ ($P < 0.001$ each), and RPE ($P < 0.01$ each) were significantly higher, and sweat loss ($P < 0.001$ each) was significantly lower compared to the CES and P EUH trials. At the end of the 1-h recovery period, subjects in the DEH trial produced significantly less urine volume ($P < 0.006$; CES vs. DEH and $P < 0.001$; P EUH vs. DEH) whereas urine specific gravity ($P < 0.004$ CES vs. DEH and $P < 0.001$ P EUH vs. DEH), urine color ($P < 0.001$ each), and urine osmolality ($P < 0.001$ each) were significantly greater compared to the CES and P EUH trials. All urine variables remained altered by DEH at halftime of the basketball protocol (urine volume: $P < 0.005$; CES vs. DEH and $P < 0.001$; P EUH vs. DEH, urine color: $P < 0.001$ each, urine specific gravity: $P < 0.001$ each, urine osmolality: $P < 0.001$ each). At the end of the fourth quarter urine specific gravity ($P < 0.01$; CES vs. DEH and $P < 0.009$; P EUH vs. DEH), urine osmolality ($P < 0.02$; CES vs. DEH and $P < 0.009$; P EUH vs. DEH), and $T_c$ ($P < 0.03$; CES vs. DEH and $P < 0.004$; P EUH vs. DEH) were significantly greater in the DEH trial compared with the CES and P EUH trials.

Responses to subjective questionnaires are presented in Figure 3.3. During both EUH trials in the chamber, subjects felt significantly less lightheaded compared to the DEH trial ($P < 0.03$; CES vs. DEH and $P < 0.02$; P EUH vs. DEH), and subjects in the CES trial felt significantly less winded ($P < 0.004$) and hot / overheated ($P < 0.02$) compared to the DEH trial. By halftime, subjects continued to feel significantly less lightheaded in the CES versus DEH ($P < 0.03$) trials and had significantly less upper-body fatigue during both EUH trials compared to the DEH ($P < 0.03$; CES vs. DEH and $P < 0.009$; P EUH vs. DEH) trial. At the end of the
basketball protocol, subjects still felt significantly less lightheaded \((P < 0.05)\) and had significantly less upper- \((P < 0.006)\) and total \((P < 0.04)\) body fatigue in the CES vs. DEH trials.

Figure 3.4 presents the single and combined long-range shooting percentages relative to the P EUH trial. Three-point shooting percentage was significantly impaired by 2% DEH compared to both EUH trials \((27 \pm 11\% \text{ vs. } 39 \pm 16 \text{ vs. } 45 \pm 13\% ; \text{ DEH vs. P EUH vs. CES})\). Compared to the DEH trial, individual shooting percentage was significantly improved by CES in the 15-foot around the world \((48 \pm 12 \text{ vs. } 64 \pm 16\%)\) and free-throw \((61 \pm 11\% \text{ vs. } 72 \pm 11\%)\) shooting drills. When shooting percentage was combined for all three drills, combined shooting percentage was significantly impaired by 2% DEH \((45 \pm 9\%)\) and significantly improved by CES intake \((60 \pm 8\%)\) compared to the P EUH trial \((53 \pm 11\%)\). There were no significant differences between trials for short range (layups; not shown in figure) shooting percentage \((92 \pm 6 \text{ vs. } 91 \pm 8 \text{ vs. } 91 \pm 9\% ; \text{ CES vs. P EUH vs. DEH})\).

The individual drill, average, and total times for sprinting tasks (relative to the P EUH trial) are illustrated in Figure 3.5. Compared with the P EUH trial \((37 \pm 4\ s)\), individual suicides sprinting times were significantly impaired by 2% DEH \((40 \pm 5\ s)\) and significantly improved by CES intake \((35 \pm 4\ s)\). Ten-widths individual sprinting times were significantly impaired by 2% DEH compared to both EUH trials \((43 \pm 5 \text{ vs. } 41 \pm 5 \text{ vs. } 41 \pm 5\ s ; \text{ DEH vs. P EUH vs. CES})\). Average sprinting times were significantly impaired by 2% DEH \((42 \pm 5\ s)\) and significantly improved by CES intake \((38 \pm 5\ s)\) compared to the P EUH trial \((39 \pm 4\ s)\). Total sprinting times showed the same pattern \((76 \pm 9 \text{ vs. } 78 \pm 9 \text{ vs. } 83 \pm 10\ s ; \text{ CES vs. P EUH vs. DEH})\).

Figure 3.6 presents the times for the individual, average, and total lateral movement drills relative to the P EUH trial. Compared to both EUH trials, 2% DEH significantly impaired performance in the zigzag \((40 \pm 4 \text{ vs. } 40 \pm 5 \text{ vs. } 43 \pm 6\ s ; \text{ CES vs. P EUH vs. DEH})\) and lane
slides (28 ± 4 vs. 29 ± 4 vs. 31 ± 4 s; CES vs. P EUH vs. DEH) drills. Compared to both EUH trials, 2% DEH significantly impaired average lateral movement (34 ± 4 vs. 34 ± 4 vs. 37 ± 4 s; CES vs. P EUH vs. DEH). Total lateral movement times showed the same pattern (68 ± 7 vs. 68 ± 8 vs. 73 ± 8 s; CES vs. P EUH vs. DEH).

There were no significant differences in the individual full-court combination times among hydration treatments. Individual key combination times were significantly impaired by 2% DEH compared to both EUH trials (47 ± 6 vs. 45 ± 6 vs. 45 ± 6 s; DEH vs. P EUH vs. CES; \( P = 0.003 \) and \( P = 0.0001 \), respectively). Average defensive drill times (average of individual full-court combination and individual key combination) were significantly faster in the CES vs. DEH trials (39 ± 5 vs. 41 ± 5 s; \( P = 0.008 \)). Total defensive drill times (sum of individual full-court combination and individual key combination) showed the same pattern (77 ± 10 vs. 82 ± 10 s; \( P = 0.006 \)). There were no significant differences between trials in time to complete 10 vertical jumps (9 ± 3 s; for all trials) or maximum vertical jump height (68 ± 15 vs. 66 ± 13 vs. 66 ± 13 cm; CES vs. P EUH vs. DEH).

**Discussion**

The main findings from this study were that: 1) deterioration in basketball skill performance in skilled 12- to 15-yr-old boys accompanied 2% DEH; and 2) EUH with a 6% CES significantly improved shooting skill performance and on-court sprinting in this subject population over EUH with a P. Subjectively, adding 6% carbohydrate (CES EUH) resulted in diminished feelings of fatigue and lightheadedness by the end of the simulated game compared with the 2% DEH trial.
Negative Effects of Dehydration

DEH is common in adolescents during team sports, with children routinely losing 1-3% of their initial BW (27; 33; 39). In the sport of basketball, even though players have opportunities to drink during time-outs and when players are substituted, they may still be unable to maintain fluid balance (27). The present study indicates that DEH as minimally as 2% of initial BW impairs basketball shooting, sprinting, and lateral movement skill performance compared to EUH with a flavored-water P in 12- to 15-yr-old boys.

Hoffman et al. (63) found no significant differences between fluid-ingestion and fluid-restricted trials in vertical jump height (which is in agreement with the present study) or in basketball shooting performance (which is at odds with the present study) when testing 17-yr-old basketball players. In the Hoffman et al. study, all subjects began the simulated basketball game euhydrated and ended the fluid-restricted trials with a 2% BW deficit; in the present study, subjects at the start of the basketball drill protocol were either euhydrated or 2% DEH. Therefore, the level of DEH in the present study is likely to reflect pre- and post-game BW deficits common to the sport of basketball. Compared with the Hoffman et al. study, it is difficult to differentiate whether the diminution in shooting skill performance in the present study is attributed to the slightly greater % DEH at the start of and throughout the basketball protocol and/or younger age of the subjects (12-15 vs. 17 yrs; present study vs. Hoffman et al.). However, given that children often show up to sport competitions already dehydrated by 1-2% (165), the level of DEH incurred during team sports may be greater than what has already been reported. Thus, it is important to educate children on developing proper hydration strategies which will enhance their health, well-being, and performance. Another possible explanation for the inconsistencies between the two studies is that the prior bout of exercise in the present study
is likely to have depleted participants' muscle glycogen concentrations to a greater extent prior to the skills test than in the study of Hoffman et al..

Thermoregulation in a dehydrated child or teen may be less efficient than in an adult. Children have a lower sweating rate per sweat gland, a lower cardiac output, smaller blood volume, more generated metabolic heat and a greater $A_D / mass$ ratio which could result in greater relative fluid loss when compared to adults (49). In boys, previous research has reported that each 1% BW loss is accompanied by a 0.28°C increase in $T_c$ (15). Findings from the present study are consistent with this statement ($\hat{y} = 0.69 + 0.31x; r = 0.68$). The greater HR and $T_c$ in the DEH vs. EUH trials at the end of the chamber and basketball protocols support previous research showing that a loss of as little as 2% BW results in elevated HR (3) and $T_c$ (15) compared with EUH during exercise in those two studies. In addition, subjects perceived the intermittent exercise bouts in the heat (chamber protocol) to be more difficult as determined by their RPE values. This suggests that exercise at even low levels of hypohydration results in greater physiological and psychological stress.

**Beneficial Effects of 6% Carbohydrate**

Several studies in adults have investigated the effect of CES intake on exercise/sport performance. Ingestion of a CES has been shown to improve tennis stroke performance at the end of prolonged play (160), results in faster 20-m sprint times (167), increases the number of sprints performed during a soccer game (58), delays time to fatigue during intermittent, high-intensity cycling (38), and improves endurance-running capacity during prolonged intermittent exercise (109) versus P EUH. The faster sprint times and improvement in sport-specific skill
performance found in the present study is in agreement with previous findings and extend these findings to a novel population of young athletes.

The present study indicates that EUH with a 6% CES significantly improved shooting skill performance over EUH with water alone. Various factors may have contributed to this improvement in performance. At halftime, subjects had significantly lower subjective feelings of upper-body fatigue in the CES EUH vs. P EUH trial. In addition, although the present study did not directly measure cognitive performance, it is interesting to consider the role alterations in mental state might have on physical performance. A loss of as little as 2% of initial BW results in deterioration in mental function with respect to memory and coordination (146). Welsh et al. (167) found that CES ingestion improved mental function compared with P ingestion during intermittent exercise designed to simulate the stop-and-go nature of competitive team sports. It was shown that during the CES trial, individuals maintained speed while also maintaining accuracy and control of their motor-skill performance; in the P EUH trial, with decrements in central control, subjects slowed down the speed at which they performed the task in order to maintain the same level of accuracy. The relative contribution of peripheral versus central fatigue to deteriorations in basketball performance is not known, and research is needed to address this issue.

Limitations

Due to the design of the study, the results clearly show the benefit of EUH vs. 2% DEH and ingesting a carbohydrate solution vs. water on basketball skill performance in 12- to 15-yr-old boys. However, when comparing 2% DEH vs. CES EUH, it is difficult to make a direct
comparing to distinguish pure hydration effects from those associated with carbohydrate intake and maintenance of blood glucose, whether dehydrated or not.

Although subjects were encouraged to stay well hydrated the day before each trial, baseline urine specific gravity and urine osmolality values indicate that some subjects may have begun the protocol dehydrated. Therefore the 2% DEH induced by the exercise protocol may have exacerbated a mild preexisting DEH condition. This supports previous findings from Walker et al., which showed that children often show up to sport competitions already dehydrated by 1-2% (165).

The present study used a double-blind experimental design. Subjects and investigators were well blinded to P EUH vs. CES trials; however, it was difficult to blind both subjects and investigators to the DEH vs. EUH trials.

In summary, basketball performance is impaired by 2% DEH in 12- to 15-yr-old boys. Fluid replacement is critical to ameliorate the deterioration in performance and physiological function that accompanies DEH. EUH with a 6% CES significantly improved shooting skill performance and on-court sprinting over EUH with water alone. This degree of improvement is important in a sport where subtle changes in skill performance could be the deciding factor in winning or losing a basketball game.
Table 3.1: Subject characteristics

<table>
<thead>
<tr>
<th>Boys (N=15)</th>
<th>means ± SD</th>
<th>range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yrs)</td>
<td>13.5 ± 1.3</td>
<td>12 - 15</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>171 ± 8</td>
<td>158 – 185</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>65.3 ± 14.4</td>
<td>43.2 – 89.3</td>
</tr>
<tr>
<td>Body Fat (%)(^a)</td>
<td>10.5 ± 2.9</td>
<td>7 – 14</td>
</tr>
<tr>
<td>Playing Experience (yrs)(^b)</td>
<td>7.4 ± 2</td>
<td>4 – 11</td>
</tr>
<tr>
<td>Max Vertical Jump (cm)</td>
<td>59.1 ± 11.3</td>
<td>41.9 – 76.2</td>
</tr>
<tr>
<td>(\dot{\text{V}}\text{O}_{2}\max) (ml ·kg(^{-1})·min(^{-1}))(^c)</td>
<td>50.0 ± 8.1</td>
<td>34 - 67</td>
</tr>
</tbody>
</table>

\(\dot{\text{V}}\text{O}_{2}\max\) = maximal oxygen consumption,  
\(^a\) triceps and calf equation; Slaughter et al. (151),  
\(^b\) number of years subject reported playing competitive basketball  
\(^c\) extrapolated from submax peak.
Table 3.2. Physiological and RPE variables

<table>
<thead>
<tr>
<th></th>
<th>HR (bpm)</th>
<th>Tc (°C)</th>
<th>MAP (mmHg)</th>
<th>RPE</th>
<th>SL (ml)</th>
<th>Uvol (ml)</th>
<th>Ucol</th>
<th>Usg (UG)</th>
<th>Uosmol (mosmol)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CES</td>
<td>92 ± 15</td>
<td>36.90 ± 0.34</td>
<td>87 ± 7.1</td>
<td></td>
<td>68 ± 84</td>
<td>5 ± 1.2</td>
<td>1.026 ± 0.01</td>
<td>891 ± 146</td>
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</tr>
<tr>
<td>P</td>
<td>90 ± 13</td>
<td>36.89 ± 0.41</td>
<td>88 ± 8.6</td>
<td></td>
<td>100 ± 101</td>
<td>5 ± 1.5</td>
<td>1.023 ± 0.01</td>
<td>792 ± 171</td>
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<tr>
<td>DEH</td>
<td>91 ± 15</td>
<td>36.89 ± 0.24</td>
<td>86 ± 9.5</td>
<td></td>
<td>70 ± 84</td>
<td>5 ± 1.2</td>
<td>1.026 ± 0.01</td>
<td>873 ± 187</td>
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<tr>
<td>Chamber</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>CES</td>
<td>142 ± 16</td>
<td>37.79 ± 0.43</td>
<td>94 ± 8.3</td>
<td>13 ± 1.7</td>
<td>493 ± 129</td>
<td>77 ± 29</td>
<td>6 ± 1.1</td>
<td>1.027 ± 0.01</td>
<td>937 ± 125</td>
</tr>
<tr>
<td>P</td>
<td>139 ± 17</td>
<td>37.54 ± 0.41</td>
<td>92 ± 7.7</td>
<td>13 ± 1.4</td>
<td>490 ± 138</td>
<td>98 ± 63</td>
<td>6 ± 1.5</td>
<td>1.025 ± 0.01</td>
<td>882 ± 140</td>
</tr>
<tr>
<td>DEH</td>
<td>160 ± 17*†</td>
<td>38.22 ± 0.37*†</td>
<td>93 ± 7.7</td>
<td>14 ± 2.2*†</td>
<td>310 ± 138*†</td>
<td>70 ± 45</td>
<td>6 ± 1.2</td>
<td>1.028 ± 0.01*†</td>
<td>931 ± 124*†</td>
</tr>
<tr>
<td>Recovery</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>CES</td>
<td>78 ± 14</td>
<td>36.91 ± 0.36</td>
<td>81 ± 8.0</td>
<td></td>
<td>50 ± 54</td>
<td>126 ± 89</td>
<td>4 ± 1.6</td>
<td>1.017 ± 0.01</td>
<td>541 ± 360</td>
</tr>
<tr>
<td>P</td>
<td>71 ± 11</td>
<td>36.91 ± 0.32</td>
<td>80 ± 7.3</td>
<td></td>
<td>63 ± 111</td>
<td>144 ± 104</td>
<td>3 ± 1.6</td>
<td>1.016 ± 0.01</td>
<td>479 ± 319</td>
</tr>
<tr>
<td>DEH</td>
<td>78 ± 16</td>
<td>36.99 ± 0.36</td>
<td>81 ± 8.0</td>
<td></td>
<td>50 ± 82</td>
<td>49 ± 35*†</td>
<td>6 ± 1.4*†</td>
<td>1.027 ± 0.01*†</td>
<td>980 ± 121*†</td>
</tr>
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<td>Quarter 2</td>
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<tr>
<td>CES</td>
<td>187 ± 10</td>
<td>38.25 ± 0.72</td>
<td>14 ± 1.8</td>
<td>349 ± 188</td>
<td>102 ± 86</td>
<td>3 ± 1.3</td>
<td>1.012 ± 0.01</td>
<td>334 ± 298</td>
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<tr>
<td>P</td>
<td>183 ± 14</td>
<td>38.10 ± 0.43</td>
<td>14 ± 1.3</td>
<td>334 ± 203</td>
<td>122 ± 89</td>
<td>2 ± 1.2</td>
<td>1.011 ± 0.01</td>
<td>305 ± 281</td>
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</tr>
<tr>
<td>DEH</td>
<td>186 ± 7</td>
<td>38.43 ± 0.38</td>
<td>15 ± 1.6</td>
<td>251 ± 106</td>
<td>27 ± 9*†</td>
<td>5 ± 1.5*†</td>
<td>1.028 ± 0.01*†</td>
<td>976 ± 99*†</td>
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<tr>
<td>Quarter 4</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>CES</td>
<td>190 ± 9</td>
<td>38.26 ± 0.40</td>
<td>15 ± 1.7</td>
<td>915 ± 324</td>
<td>23 ± 31</td>
<td>5 ± 1.9</td>
<td>1.019 ± 0.01</td>
<td>505 ± 207</td>
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<tr>
<td>P</td>
<td>186 ± 10</td>
<td>38.14 ± 0.43</td>
<td>15 ± 1.4</td>
<td>788 ± 399</td>
<td>42 ± 71</td>
<td>4 ± 1.9</td>
<td>1.019 ± 0.01</td>
<td>478 ± 249</td>
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</tr>
<tr>
<td>DEH</td>
<td>191 ± 11*</td>
<td>38.64 ± 0.35*†</td>
<td>15 ± 2.0</td>
<td>608 ± 219†</td>
<td>6 ± 4*</td>
<td>6 ± 1.3*</td>
<td>1.030 ± 0.01*†</td>
<td>764 ± 118*†</td>
<td></td>
</tr>
</tbody>
</table>

Values are mean ± SD at end of each time period. CES, 6% carbohydrate-electrolyte drink trial; P EUH, flavored-water placebo drink trial; DEH, 2% dehydration trial; HR, heart rate; Tc, core body temperature; MAP, mean arterial pressure; RPE, rating of perceived exertion; SL, sweat loss; Uvol, urine volume; Ucol, urine color; Usg, urine specific gravity; Uosmol, urine osmolality.

*P < 0.05, DEH vs. P EUH. †P < 0.05, CES vs. DEH.
Figure 3.1.

<table>
<thead>
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<th></th>
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</thead>
<tbody>
<tr>
<td>Time (min)</td>
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<td>20</td>
<td>35</td>
<td>40</td>
<td>55</td>
<td>60</td>
</tr>
</tbody>
</table>

| Time (min) | 75 | 80 | 95 | 100 | 115 |

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Tc, RPE, HR, BP</th>
<th>Tc, RPE, HR, BP</th>
<th>Tc, RPE, HR, BP</th>
<th>Tc, RPE, HR, BP</th>
<th>Tc, RPE, HR, BP</th>
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</thead>
<tbody>
<tr>
<td>Time (min)</td>
<td>135</td>
<td>150</td>
<td>165</td>
<td>180</td>
<td>195</td>
</tr>
</tbody>
</table>

**Figure 3.1.** Schematic of study design for each trial. Tread, treadmill; Bicyc, cycle ergometer; Rec, recovery; Qtr, basketball quarter; BW, body weight; Tc, core body temperature; HR, heart rate; BP, blood pressure; UR, urine sample; Vol, volume of fluid ingested; S, survey; RPE, rating of perceived exertion.
Figure 3.2. Schematic of continuous basketball drills protocol designed to simulate a game with four 12-min quarters and a 10-min halftime rest. The drills performed in the third quarter were the same as the first quarter (A-F), and the fourth quarter drills were the same as the second quarter (G-L). See methods for a detailed description of each drill.
Figure 3.3. Responses to subjective questionnaires on 100-point scales. Only scales yielding significant effects are presented. DEH, 2% dehydration trial; P, flavored-water placebo drink trial; CES, 6% carbohydrate-electrolyte drink trial. *$P < 0.05$. 
Figure 3.4. Boxplots of individual and combined (around the world, 3-point and free-throw shots) long-range shooting percentages relative to the P EUH. The top, bottom, and line through the middle of the box correspond to the 75th percentile (top quartile), 25th percentile (bottom quartile), and 50th percentile (median), respectively. The whiskers on the bottom extend from the 10th percentile (bottom decile) and top 90th percentile (top decile). 2% DEH, 2% dehydration prior to testing; CES, carbohydrate-electrolyte drink; mean values for the P EUH trial (the basis for each relative comparison) is shown at the right of each panel.
Figure 3.5. Boxplots of individual, average (average of the suicides and 10-widths single performance scores), and total (sum of the suicides and 10-widths single performance scores) sprint times relative to the P EUH. The top, bottom, and line through the middle of the box correspond to the 75th percentile (top quartile), 25th percentile (bottom quartile), and 50th percentile (median) respectively. The whiskers on the bottom extend from the 10th percentile (bottom decile) and top 90th percentile (top decile). 2% DEH, 2% dehydration prior to testing; CES, carbohydrate-electrolyte drink; mean values for the P EUH trial (the basis for each relative comparison) is shown at the right of each panel.
Figure 3.6. Boxplots of individual, average (average of the zigzags and lane slides single performance scores), and total (sum of the zigzags and lane slides single performance scores) lateral movement times relative to the P EUH. The top, bottom, and line through the middle of the box correspond to the 75th percentile (top quartile), 25th percentile (bottom quartile), and 50th percentile (median) respectively. The whiskers on the bottom extend from the 10th percentile (bottom decile) and top 90th percentile (top decile). 2% DEH, 2% dehydration prior to testing; CES, carbohydrate-electrolyte drink; mean values for the P EUH trial (the basis for each relative comparison) is shown at the right of each panel.
Chapter 4

RESPONSES OF LEAN AND OBESE BOYS TO REPEATED SUMMER EXERCISE-HEAT BOUTS

Introduction

Heat-acclimatization (induced in a natural environment) and acclimation (induced over a shorter period of time, often in a laboratory setting) result from repeated heat exposures which sufficiently increase $T_c$ and $T_{sk}$, and stimulate abundant sweating (168). In response, the body adapts through numerous physiological adjustments such as reductions in day-to-day exercise $T_c$, HR and $T_{sk}$, an increase in sweating rate, earlier onset of sweating with more dilute sweat, and an increase in plasma volume (144). In addition, decreases in baseline $T_c$ have been observed following humid heat-acclimation (28). The induction of heat-acclimation during exercise is specific to the duration of exposure, environmental conditions, and intensity of exercise and can be attained in adults in 5-10 days through exercise / heat exposures lasting 1-2 hrs each day (144).

While both children and adults are able to acclimate to exercise in the heat, children acclimate at a slower rate (64) and attain a degree of acclimation that is somewhat lower (164) than adults. Only two studies (61; 62) have investigated the responses of obese / overweight vs. lean children to exercise in the heat, with both studies demonstrating no difference in heat tolerance (exercise time in the heat before a $T_c$ of 39.4°C was reached) between groups. However, although all subjects in both studies underwent 3 exercise / heat-acclimation sessions prior to the heat tolerance trials, these data were not presented or discussed. Thus, neither the
relative ability of obese vs. lean children to acclimate to exercise in the heat nor a comparison of their rates of acclimation has been investigated.

In adults, exposure to summer heat confers some degree of natural acclimatization. During both passive heat stress and exercise in the heat, $T_c$ and HR are lower and sweating is more profuse and dilute in summer compared to winter months (168). Due to this natural acclimatization, full artificially-induced heat-acclimation in a warm environment occurs more rapidly (46). A high degree of fitness also hastens the acclimation process (128). Children indigenous to tropical climates display high sweating rates, and a heat tolerance similar to adults during exercise in the heat (123; 124). However, for both obese and lean children residing in more temperate climates, the degree of natural acclimatization incurred during the summer months and its impact on subsequent acclimation-related changes when exposed to regular exercise / heat exposures are unknown.

The purpose of this study was to determine the degree of initial natural acclimatization and subsequent artificially-induced acclimation-related changes during repeated exercise-heat bouts in 7 lean and 7 obese 9- to 12-yr-old boys during the warm summer months. It was hypothesized that obese children would: 1) be less naturally acclimatized to the heat as shown by significantly higher baseline $T_c$; and 2) display a significantly slower time course for the classic markers of acclimation (e.g., day-to-day decreases in exercise $T_c$ and HR, elevations in sweating rate) during repeated days of light-to-moderate intensity exercise in a warm, humid environment.
Methods

Subjects

This study was approved by the Institutional Review Board of The Pennsylvania State University. Seven lean and 7 obese 9- to 12-yr-old boys volunteered to participate in this study. Lean and obese were defined as ≤ 20% and ≥ 25% body fat, respectively (86) as measured by whole body dual energy X-ray absorptiometry scan (model QDR 4500W, Hologic, Waltham, MA). Each subject and his parent/guardian were advised of all experimental procedures and associated risks before verbal assent was given by the child and a written informed consent was provided by the parent/guardian. All subjects were healthy, normotensive, and not taking any medications that could affect their cardiovascular or thermoregulatory responses. Preliminary screening included blood chemistry analysis (CHEM-24, complete blood count and lipid profile, Quest Diagnostics), and resting 12-lead electrocardiogram. During a \( \dot{V}O_2\text{max} \) test on a treadmill, subjects began at a self-selected speed to elicit a HR of ~140- to 150-bpm at 0% grade, followed by an increase in slope of 2% until two of the following four criteria were met: 1) a plateau in \( \dot{V}O_2 \) defined as an increase of ≤ 2.0 ml/kg/min; 2) a HR > 195 bpm; 3) a respiratory exchange ratio (RER) > 1.0; or 4) subjective indicators of fatigue such as hyperpnea, facial flushing, unsteady gait and refusal of the child to exercise further (56; 113). Subjects completed a physical exam during which a clinician determined pubertal status according to the criteria of Tanner (152). Subject characteristics are presented in Table 1.

A minimum of 8-h before each test, subjects swallowed an ingestible temperature sensor (CorTemp, HQ Inc, Palmetto, Fla) for the measurement of \( T_c \). The sensor is a single-use, pill-shaped electronic device that contains a telemetry system, a microbattery, and a quartz crystal whose frequency of vibration is linearly related to temperature. Each temperature sensor was
calibrated by the manufacturer, which provides a serial number that is programmed into a handheld recorder (CT2000), ensuring an accuracy of 0.1°C. Each pill was used within 6 months from the date it was shipped by the manufacturer. During steady state exercise in a warm environment, the temperature and response time of the ingestible temperature sensor falls between that of rectal and esophageal temperatures (112).

**Testing Procedures**

Subjects were asked to refrain from caffeine consumption on each day of the experiment and reported to the lab at least 2-h after a meal. After providing a urine sample, the subject was instrumented with a Polar® HR monitor, belt and pouch to attach the handheld recorder (CT2000) to the subject for continuous Tc measurement and weighed (Seca 770, accuracy ± 50 g) wearing only shorts (all subsequent weights were taken wearing shorts only).

A total of six 70-min acclimation sessions were completed by each subject on separate days. During each trial, 2 subjects were test concurrently, 1 lean and 1 obese, in order to control for early / late summer seasonal variations. Testing began in the beginning of June and concluded by early September. Local weather for this period averages from 22 to 28°C (71 to 82°F; NOAA, 2007). For all experimental trials the time between each scheduled test day was no more than 2 days. Subjects were encouraged to stay well-hydrated the day before each trial. For all experimental trials, subjects wore shorts, socks and sneakers. Since experiments were conducted in the summer months, subjects were partially heat-acclimatized due to routine outdoor activities (168). Thus, baseline Tc in lean and obese children were measured and compared to assess the degree of natural acclimatization. Subsequently, each subject completed 6 acclimation sessions in order to compare physiological responses between lean and obese boys.
during repeated exercise / heat bouts from the partially heat-acclimatized state. Attainment of acclimation was defined by a similar final Tc for two consecutive sessions and a leveling off of Tc within the last exercise bout (all subjects completed 6 trials). A schematic of the experimental design is diagrammed in Figure 4.1.

During each session, subjects exercised at 30% of \( \dot{V}O_{2\text{max}} \) alternating between a treadmill (Precor USA C962) and cycle ergometer (Monark Ergomedic 818E) for three 20-min bouts interspersed with 5-min rests. Environmental conditions were held constant at 38°C, 50% relative humidity. During school recess and spontaneous playtime, children spend a majority of the time participating in light-to-moderate intensity activities (121; 122); thus this exercise intensity was chosen because it reasonably simulates an intensity typical of a child during spontaneous physical exertion and of heat-acclimation studies. BW was measured during each rest period and the subject was given water to maintain BW by replacing all water lost through sweat. The experiment ended when the subject either completed the protocol, if the Tc exceeded 39°C, if the subject experienced adverse signs (nausea, dizziness, etc.), or if the subject desired to stop. After exiting the chamber at the conclusion of the experiment, a post-experiment urine sample was obtained.

Measurements

All HR, and Tc data were measured continually through the protocol and stored as 1-min averages using computer software (Labview) in conjunction with a data-acquisition system (National Instruments, Austin, TX). BP by brachial auscultation (sphygmomanometry) was measured 10-min into each exercise bout. To ensure that each subject was working at the desired workload, expired air was measured 10-min into the second exercise bout for 5-min for
the determination of \( \dot{V}O_2 \) (TrueOne 2400 Metabolic Measurement System, ParvoMedics, Salt Lake City, UT). Urine volume was measured with a graduated cylinder and urine color was determined by holding each specimen container next to a validated color scale (8) in a well-lit room. The eight-color scale ranges from very pale yellow (#1) to brownish green (#8). Urine osmolality (freezing point depression, Advanced DigiMatic Osmometer Model 3D2), and specific gravity (Refractometer, Atago A300CL) were determined in triplicate. Sweating rate was calculated from the net change in BW corrected for fluid consumption and urine excreted.

**Subjective Ratings**

During the preliminary screening, the Physical Activity and Sports Competence subscales of the Physical Self Description Questionnaire, which has been validated for use in adolescents (90-92), was completed to subjectively determine how “active” each subject perceived himself to be on a daily / weekly basis. Each item is a simple declarative statement, all positively worded, and subjects respond on a 6-point true-false response scale where 1 = “false”, 2 = “mostly false”, 3 = “more false than true”, 4 = “more true than false”, 5 = “mostly true”, and 6 = “true”. The statements to which the subjects responded were, “Several times a week I exercise or play hard enough to breathe hard (to be out of breath)”, “Other people think that I am good at sports”, “I often do exercise or activities that make me breathe hard”, “I am good at most sports”, “I get exercise or do sports activities 3 or 4 times a week that make me breathe hard and last at least 30 minutes”, “I do physically active things (like jogging, dancing, bicycling, aerobics, gym or swimming) at least three times a week”, “I have good sports skills”, “I do lots of sports, dance, gym or other physical activities”, “I am better at sports than most of my friends”, “I do sports, exercise, dance or other activities almost every other day”, and “I play sports well”. During each
experiment, RPE, (Borg scale (26)) and thermal sensation ((TS), using a 0-8 scale in which 0 = unbearable cold, 4 = thermoneutral, and 8 = unbearably hot (174) were measured 10-min into each exercise bout.

Statistical Analyses

A repeated measures analysis of covariance was used to fit a model to the data by SAS PROC MIXED. This linear mixed model took into account the correlated nature of the repeated measures. Group was treated as a fixed effect and subjects were treated as random effects. The independent variables were group, time and day (where appropriate) and the dependent variable was the measured physiological response. When making multiple comparisons, Bonferroni adjustments were used. Results were considered significant at P < 0.05.

During exercise in the heat, whereas metabolic heat production is a reflection of absolute intensity, heat loss mechanisms are a function of relative intensity. Thus, heat storage and the subsequent rise in $T_c$ is dependent to some degree upon both absolute and relative intensities (72). In the present study, work at the same relative intensity was the logical choice in order to investigate differences in heat loss mechanisms between lean and obese boys. However, to investigate the impact of absolute vs. relative intensity, 4 lean and 3 obese subjects repeated the first heat-acclimation trial which matched the absolute and relative workloads of the lean and obese groups (i.e. decreasing the workload for the lean group to match the obese group and increasing the workload for the obese group to match the lean group). The time between the completion of the 6th heat-acclimation trial and the repeat heat-acclimation trial was > 2 months.
Results

Responses to the Physical Activity and Sports Competence subscales of the Physical Self Description Questionnaire are presented in Figure 4.2. Compared to lean subjects, obese subjects perceived themselves to be significantly less active (P < 0.03) as determined by significantly lower ratings to the following questions: “Several times a week I exercise or play hard enough to breath hard (to be out of breath)” (P < 0.03), “I get exercise or do sports activities 3 or 4 times a week that make me breath hard and last at least 30 minutes” (P < 0.02), “I do lots of sports, dance, gym or other physical activities” (P < 0.003). In addition, obese subjects reported feeling significantly less competent playing sports (P < 0.03) as indicated by significantly lower ratings to the following questions: “Other people think that I am good at sports” (P < 0.008), “I have good sports skills” (P < 0.02), “I play sports well” (P < 0.03).

Six lean and 2 obese subjects were classified as pre-pubertal (Tanner stage 1), 5 obese subjects were classified as mid-pubertal (Tanner stage 2-4) and 1 lean subject was classified as late-pubertal (Tanner stage 5). As expected, obese subjects weighed more, had a higher A_D, a lower A_D / mass ratio, higher percent body fat, and a lower VO_{2max} (all P < 0.05; Table 4.1). Body fatness ranged from 14 to 20% in the lean subjects and from 28 to 45% in the obese subjects. The measured exercise intensity ranged from 27.6 ± 0.5% to 35.3 ± 1.0% for the lean subjects and 27.5 ± 1.2% to 35.5 ± 0.5% for the obese subjects across trials (P > 0.05).

Baseline, final exercise and change in T_c per trial by day of acclimation are presented in Table 4.2. On day 1, obese subjects were less naturally acclimatized as indicated by a significantly higher baseline T_c (P < 0.004). By day 6 compared to day 1, significant reductions in baseline T_c were evident in both groups (both P < 0.05), occurring at a similar rate (baseline T_c day 6 – day 1; P > 0.05). Obese subjects continued to have significantly higher baseline T_c on
days 2 through 6 (all $P < 0.05$). Baseline $T_c$ in obese subjects by day 6 was similar to that of lean subjects on day 1 ($P > 0.05$).

Compared to day 1, significant reductions in exercising $T_c$ throughout the entire protocol were evident by day 6 in both groups (Figure 4.3; both $P < 0.001$), occurring at a significantly slower rate (final exercise $T_c$ day 6 – day 1) in obese vs. lean subjects (Table 4.2, $P < 0.05$). The change in $T_c$ per trial (ending – beginning $T_c$) was significantly lower in lean subjects on day 5 and 6 compared to day 1 (Table 4.2; $P < 0.05$) but not in obese subjects ($P > 0.05$). For both groups, there were no significant differences in $T_c$ between day 5 and 6 (final $T_c$ during exercise day 5 vs. day 6; obese $= 37.96 \pm 0.05$ vs. $37.89 \pm 0.05$, lean $= 37.78 \pm 0.07$ vs. $37.72 \pm 0.06^\circ C$ $P > 0.05$), suggesting attainment of heat-acclimation according to the operationally defined criteria of a similar final $T_c$ for two consecutive sessions and a clear plateau in $T_c$ during the last exercise bout (Figure 4.3).

The Bland-Altman approach to measuring agreements for repeated measures was used to determine the agreement of $T_c$ between the first (relative exercise intensity) and repeated (absolute exercise intensity) heat-acclimation trials using $\pm 0.3^\circ C$ as the physiological threshold for assessment. This threshold takes into account the anticipated standard deviation for $T_c$ measurement in boys of this age (17). The mean difference between the two trials was $0.01^\circ C$ and the standard deviation of the difference between the two trials was $0.08^\circ C$. The 95% limits of agreement were -0.1503 to 0.1621. Therefore, when matched for absolute and relative exercise intensity, the difference in $T_c$ was within acceptable limits and considered marginal. This suggests that other factors independent of exercise intensity contribute to significant differences observed in the present study.
A significant reduction in HR from day 1 to day 6 occurred in the lean (P < 0.001) but not the obese subjects (Figure 4.4). The change in HR per trial (ending – beginning $T_c$) was significantly different between groups within each trial (P < 0.01), but not between-day within each group (change in HR day 1 vs. 6; obese = 26 ± 4 vs. 31 ± 6, lean = 39 ± 5 vs. 37 ± 3). Obese subjects had a significantly lower relative ($\text{ml} \cdot \text{m}^{-2} \cdot \text{h}^{-1}$) but not absolute ($\text{ml} \cdot \text{h}^{-1}$) sweating rate compared to lean subjects across all days (Table 3; P < 0.01). No urine variable was significantly different between groups.

Subjective responses to the exercise in the heat bouts on days 1 through 6 are presented in Table 4.4. At all time points on days 3 through 6, RPE were significantly higher in obese subjects. In lean subjects, a significant reduction in RPE occurred at min 35 and 60 on day 6 compared to day 1 and in TS at all time points on days 3 through 6.

**Discussion**

The main findings from this study are that during the summer months, obese (compared to lean) 9- to 12-yr-old boys: 1) are less naturally heat-acclimatized as indicated by significantly higher baseline $T_c$; and 2) display a significantly slower rate of decrease in exercise $T_c$ and less of an elevation in sweating rate during repeated bouts of light-to-moderate exercise at a similar relative intensity ($30\% \hat{V}O_{2\max}$) in a warm, humid environment. After 6 days of artificial heat-acclimation, baseline $T_c$ in obese children reached that of lean children on day 1, whereas by day 6 lean children acclimated to a new baseline $T_c$. Since obese children started at a higher baseline $T_c$, and acclimate at a slower rate, this suggests that they require additional exercise / heat bouts in order to achieve a degree of acclimation similar to that of lean children.
Beneficial Effects of Natural Acclimatization

Adults exposed to warm summer weather attain some degree of natural acclimatization. During both a passive heat stress and exercise in the heat, $T_c$ and HR are lower and sweating is more profuse and dilute in the summer compared to winter months (168). Experimental heat-acclimation occurs at a faster rate in both acclimatized (46) and more fit (128) adults. Physically fit adults display traits similar to that of heat-acclimatized adults during exercise in the heat (117). Pandolf et al. (114) showed that $\dot{V}O_2\text{max}$ before acclimation was directly related to the rate of drop in exercising $T_c$ over the course of heat-acclimation. Lower $T_c$ and HR, and higher sweating rates during exercise in the heat are similar for adults residing in tropical climates and those who are artificially-acclimated, compared to unacclimated controls (168).

In children, very little is known regarding the beneficial effects of natural acclimatization. Children indigenous to tropical climates display high sweating rates and a heat-tolerance similar to adults during exercise in the heat (123; 124). Although the American Academy of Pediatric guidelines (4) state that children should not perform physical activity if the WBGT is greater than 29°C, heat-acclimatized 11- to 14-yr old girl athletes are able to tolerate exercise in conditions of higher heat and humidity (WBGT = 31.9 ± 1.5°C) (32). Girls of similar aerobic capacity, hydration status, and degree of heat-acclimatization as adult women display a stable HR, stroke index and cardiac index while cycling at 60% $\dot{V}O_2\text{max}$ until fatigue in a hot and humid environment (WBGT = 29.9 ± 0.2°C) (124). Collectively, these studies suggest that children who are naturally acclimatized to tropical climates are able to effectively tolerate exercise in the heat. The present study indicates that both lean and obese children residing in more temperate climates who vary in their degree of acclimatization to the heat during the summer months are also able to tolerate exercise in the heat. On day 1, the obese boys were less
naturally acclimatized as indicated by a significantly higher baseline $T_c$ compared to lean boys. Although the Physical Activity subscale of the Physical Self Description Questionnaire in the present study did not differentiate between indoor and outdoor activity, it is likely that the higher baseline $T_c$ on day 1 in the obese subjects was due to less outdoor physical activity and thus, less natural exercise / heat exposure compared to the lean subjects.

**Heat-Acclimation**

In adults, significant reduction in resting $T_c$ following acclimation to humid heat for 7 days have been observed (28). The present study demonstrates that children show similar physiological adaptations to 6 days of humid heat-acclimation. The reduction in baseline $T_c$ in adults ranged from -0.1 to -0.5°C (28), while children tested here also fell within this range (reduction in baseline $T_c$: obese = -0.21 ± 0.06, lean = -0.23 ± 0.04). Interestingly, baseline $T_c$ in the obese children on day 6 was similar to that of lean children on day 1, whereas lean children by day 6 acclimated to a new baseline $T_c$. This suggests that with regards to heat-acclimation during the summer months, the obese children in our sample were approximately 6 acclimation days behind the lean children. Therefore, obese children require additional heat exposures in order to achieve a similar degree of acclimation as lean children, even during warm summer months.

Heat-acclimation is most effectively induced through a combination of repeated exercise / heat bouts and is essential to minimize the associated thermal and cardiovascular stress. In adults, Buskirk et al. (31) reported that during a 10-day exercise / heat-(temperatures = 46°C dry bulb; 27°C wet bulb) acclimation protocol, overweight women compared to their lean counterparts were repeatedly unable to complete three 20-min walks interspersed with 20-min
rests. In contrast, both lean and obese men tolerated the exercise / heat exposures well and were able to complete all experimental trials without incident. Lean 8- to 10-yr-old children were able to tolerate and complete repeated (7-days) acclimation bouts (temperatures = 43°C dry bulb; 24°C wet bulb), resulting in reduced cardiovascular and thermal strain (65). Only two studies (61; 62) have investigated the response of an obese / overweight vs. lean child to exercise in the heat. Both studies reported no difference in heat tolerance (exercise time in the heat before a $T_c$ of 39.4°C was reached) between lean and obese 9- to 12-yr-old children. However, although all subjects were able to complete 3 acclimation sessions (temperature range = 32 - 50°C dry bulb; 18 - 27°C wet bulb) prior to the heat tolerance trials, no acclimation data were provided. The present study indicates that although both groups were able to incur acclimation-related changes, obese children display a significantly slower rate of decrease in exercise $T_c$ and less of an elevation in sweating rate during repeated bouts of exercise in a warm, humid environment.

Although both groups began the study with different degrees of natural acclimatization, this still suggests that during the summer months, additional exercise / heat-acclimation bouts may be necessary in order for obese children to obtain a degree of acclimation similar to that of lean children.

Numerous factors may account for the slower rate of heat-acclimation during exercise in obese vs. lean children in the present study. Due to the increase in subcutaneous body fat deposits, a larger obese individual, with a smaller $A_D / mass$ ratio, loses metabolic heat generated during exercise at a slower rate than a smaller lean individual (127) thus resulting in greater heat storage. Since adipose tissue has a lower specific heat of stored lipid (0.40 kcal•kg$^{-1}$$•^oC^{-1}$ adipose tissue vs. 0.82 kcal•kg$^{-1}$$•^oC^{-1}$ entire human body) storing the same amount of heat would induce a greater rise in temperature in adipose vs. lean tissue (30). Thus, the combination of a
smaller $A_D/\text{mass}$ ratio and greater subcutaneous fat deposits may result in greater heat storage in an obese compared to lean child. Previous research has suggested that the degree of heat-acclimatization is related to body heat storage: the greater the amount of heat stored in the body, the higher the degree of heat-acclimatization (149). Others have suggested that there may be a “ceiling effect” or an optimal rate of heat storage above or below which a slower rate of acclimatization will occur (65). Although heat storage was not calculated in the present study, it is possible that the “ceiling effect” combined with the possible impaired heat dissipation mechanisms in obese vs. lean individuals discussed below contributed to the slower rate of heat-acclimation during exercise in obese vs. lean subjects in the present study.

Findings by Kuno (81) show that increases in $A_D$ cause inverse changes in sweat gland density but not in the total number, since the number of eccrine sweat glands in an individual does not change after 2 years of age. Thus the capacity for evaporative cooling in an obese child may be reduced. In the warm/humid environment of the present study, the evaporation of sweat was the primary means of heat dissipation and likely depends on the optimal sweating rate for a given unit of metabolic heat production and $A_D$. The lower sweating rates per $A_D$ in the obese vs. lean subjects in the present study may have been insufficient to maintain the evaporative heat loss necessary to match metabolic heat production, resulting in greater heat storage. However, previous research in children has reported no difference in sweating rate per $A_D$ in 9- to 12-yr-old lean vs. obese boys during four exercise in the heat tolerance tests at a similar absolute intensity after partial heat-acclimation (62), which is at odds with the present study. The same study also reported higher evaporative rates per kilogram of weight in lean vs. obese boys. Due to the differing environmental conditions and exercise intensities (absolute vs. relative) between studies, it is difficult to explain the above discrepancies and addition research is warranted.
One hallmark of heat-acclimation is a reduction in day-to-day exercising HR. It is likely that not one but a combination of several mechanisms contributes to this improvement in cardiovascular function, including expansion of plasma volume, increase in venous tone from cutaneous and noncutaneous beds, and a reduction in \( T_c \) (168). In the present study, significant reductions in exercising HR by day 6 occurred in the lean but not the obese children. Since no prior study had addressed changes in cardiovascular function during heat-acclimation in obese children, it is difficult to speculate reasons for their lack of change in HR. However, previous findings in obese adults may provide some insight. Plasma volume expansion is most likely mediated via the influx of protein from cutaneous interstitial space to vascular compartments (145). Forearm blood flow during exercise in the heat is attenuated in obese compared to lean adults (162). Thus, obese subjects may be less able to flush proteins into the vascular compartments, resulting in a lower amount of fluid shifting from the intra- to the extracellular compartments, less plasma volume expansion and subsequently, less of a reduction in HR during repeated exercise / heat bouts compared to their lean counterparts. In addition, the cardiovascular system may be compromised in an obese adult, as demonstrated by left ventricular hypertrophy accompanied by systolic or diastolic dysfunction, increased cardiac output and stroke volume both at rest and during exercise (30). In adults during acclimatization in a hot, humid environment, HR is significantly correlated with both stroke volume and \( T_c \), suggesting that both an increase in stroke volume and decrease in \( T_c \) independently are associated with the decrease in HR (173). Thus, if stroke volume was significantly higher on day 1 in obese subjects, then they may have less reserve to further increase stroke volume which would result in an attenuated decrease in HR.
In lightly-clothed adults, repeated exercise / heat-acclimation bouts at a given relative intensity decrease RPE and TS, possibly reflecting a decrease in physiological (\(T_c\) and HR) strain (6). Very little is known regarding how perceived physical effort and / or thermal comfort change in response to an exercise / heat-acclimation protocol in children. Bar-Or and Inbar (17) found a significant reduction in RPE after a 5-day exercise / heat-acclimation protocol in 8- to 10-yr-old lean boys. Findings from the present study, which demonstrates in lean children a significant reduction in RPE at min 35 and 60 on day 6 compared to day 1, supports previous research. The significant reduction in TS at all time points on days 3 through 6 compared to day 1 in lean children also suggests improved thermal comfort. In response to the heat-acclimation protocol in the present study neither RPE nor TS (except for day 6 min 35) significantly decreased in obese subjects. This might suggest that obese children require additional exercise / heat-acclimation bouts in order to achieve a similar degree of improvement in effort perception and thermal comfort as lean children. In addition, the present study indicates that obese compared to lean children have significantly higher RPE values during repeated exercise / heat bouts at all time points on days 3 through 6. It is difficult to postulate factors which may have contributed to the higher RPE values (i.e. increases in ventilation, \(M\), HR, \(T_{sk}\), \(T_c\), acidity, etc.) and to differentiate the magnitude of their impact. It is interesting to note that the obese children had significantly higher RPE values 10-min into the exercise bout. The significantly higher effort perception during exercise in the heat in obese vs. lean children in the present study could suggest that obese children may require enhanced encouragement and support while exercising in the heat.

In summary, during the summer months, obese (compared to lean) 9- to 12-yr-old boys are less naturally heat-acclimatized as indicated by significantly higher baseline \(T_c\). In addition,
obese children display a significantly slower rate of decrease in exercise $T_c$ and less of an elevation in sweating rate during repeated bouts of light-to-moderate exercise in a warm, humid environment compared to their lean counterparts. This suggests that obese children require additional exercise bouts in the heat in order to achieve a degree of acclimation similar to that of lean children.
Table 4.1. Subject characteristics by group

<table>
<thead>
<tr>
<th></th>
<th>Lean Boys</th>
<th>Obese Boys</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Age, yr</td>
<td>11 ± 0.3</td>
<td>11 ± 0.2</td>
</tr>
<tr>
<td>Height, cm</td>
<td>152 ± 2</td>
<td>155 ± 1</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>42 ± 2</td>
<td>54 ± 4*</td>
</tr>
<tr>
<td>AD, m²</td>
<td>1.33 ± 0.03</td>
<td>1.50 ± 0.05*</td>
</tr>
<tr>
<td>AD/mass, m²/kg</td>
<td>0.032 ± 0.001</td>
<td>0.028 ± 0.001*</td>
</tr>
<tr>
<td>Body fat, %</td>
<td>18 ± 1</td>
<td>33 ± 2*</td>
</tr>
<tr>
<td>Lean body mass, kg</td>
<td>32 ± 1</td>
<td>33 ± 1</td>
</tr>
<tr>
<td>VO₂max, ml·kg⁻¹·min⁻¹</td>
<td>49 ± 1</td>
<td>37 ± 2*</td>
</tr>
<tr>
<td>VO₂max, L/min⁻¹</td>
<td>2.1 ± 0.1</td>
<td>2.0 ± 0.1</td>
</tr>
</tbody>
</table>

Values are means ± SE. AD, DuBois surface area; VO₂max, maximal aerobic capacity. *Significantly different from lean boys, P < 0.05.
Table 4.2. Baseline, final exercise and change in $T_c$ by day of acclimation

<table>
<thead>
<tr>
<th></th>
<th>Day 1</th>
<th>Day 2</th>
<th>Day 3</th>
<th>Day 4</th>
<th>Day 5</th>
<th>Day 6</th>
<th>Day 6 – Day 1</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Baseline $T_c$, °C</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lean</td>
<td>37.41 ± 0.06</td>
<td>37.28 ± 0.06</td>
<td>37.35 ± 0.04</td>
<td>37.30 ± 0.06</td>
<td>37.22 ± 0.04†</td>
<td>37.18 ± 0.04†</td>
<td>-0.23 ± 0.04</td>
</tr>
<tr>
<td>Obese</td>
<td>37.62 ± 0.06*</td>
<td>37.44 ± 0.08*</td>
<td>37.47 ± 0.10*</td>
<td>37.47 ± 0.08*</td>
<td>37.45 ± 0.05*</td>
<td>37.41 ± 0.04*†</td>
<td>-0.21 ± 0.06</td>
</tr>
<tr>
<td><strong>Final Exercise $T_c$, °C</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lean</td>
<td>38.17 ± 0.09</td>
<td>37.99 ± 0.06†</td>
<td>37.95 ± 0.05†</td>
<td>37.87 ± 0.06†</td>
<td>37.78 ± 0.07†</td>
<td>37.72 ± 0.06†</td>
<td>-0.45 ± 0.08</td>
</tr>
<tr>
<td>Obese</td>
<td>38.15 ± 0.05</td>
<td>38.19 ± 0.08</td>
<td>38.06 ± 0.06</td>
<td>38.07 ± 0.07</td>
<td>37.96 ± 0.05†</td>
<td>37.89 ± 0.05†</td>
<td>-0.26 ± 0.04*</td>
</tr>
<tr>
<td><strong>$\Delta$ $T_c$ per trial, °C</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lean</td>
<td>0.77 ± 0.08</td>
<td>0.72 ± 0.06</td>
<td>0.60 ± 0.04</td>
<td>0.58 ± 0.02†</td>
<td>0.56 ± 0.04†</td>
<td>0.54 ± 0.02†</td>
<td>-0.23 ± 0.09</td>
</tr>
<tr>
<td>Obese</td>
<td>0.53 ± 0.07</td>
<td>0.76 ± 0.12</td>
<td>0.58 ± 0.10</td>
<td>0.61 ± 0.11</td>
<td>0.51 ± 0.06</td>
<td>0.48 ± 0.08</td>
<td>-0.05 ± 0.07</td>
</tr>
</tbody>
</table>

Values are means ± SE for 7 lean and 7 obese subjects. $T_c$, body core temperature; $\Delta T_c =$ Final Exercise $T_c$ – Baseline $T_c$.

*Significant group difference at $P < 0.05$. †Significantly different from day 1 at $P < 0.05$. 
### Table 4.3. Sweating rate during repeated exercise-heat bouts by day of acclimation

<table>
<thead>
<tr>
<th></th>
<th>Sweating Rate, ml·h⁻¹</th>
<th>Sweating Rate, ml·m⁻²·h⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lean</td>
<td>Obese</td>
<td>Lean</td>
</tr>
<tr>
<td>Day 1</td>
<td>316 ± 44</td>
<td>312 ± 37</td>
</tr>
<tr>
<td>Day 2</td>
<td>332 ± 40</td>
<td>334 ± 71</td>
</tr>
<tr>
<td>Day 3</td>
<td>363 ± 50</td>
<td>348 ± 31</td>
</tr>
<tr>
<td>Day 4</td>
<td>396 ± 70</td>
<td>361 ± 28</td>
</tr>
<tr>
<td>Day 5</td>
<td>411 ± 79</td>
<td>379 ± 36</td>
</tr>
<tr>
<td>Day 6</td>
<td>424 ± 56</td>
<td>416 ± 44</td>
</tr>
</tbody>
</table>

Values are means ± SE for 7 lean and 7 obese subjects.  
*Significant group difference at P < 0.01.
Table 4.4. Subjective responses to repeated exercise-heat bouts by day of acclimation

<table>
<thead>
<tr>
<th></th>
<th>RPE Lean</th>
<th>Obese</th>
<th>TS Lean</th>
<th>Obese</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Day 1</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 min</td>
<td>9 ± 1.0</td>
<td>10 ± 0.8</td>
<td>5.9 ± 0.2</td>
<td>5.4 ± 0.2</td>
</tr>
<tr>
<td>35 min</td>
<td>12 ± 1.4</td>
<td>12 ± 1.1</td>
<td>6.2 ± 0.3</td>
<td>6.2 ± 0.3</td>
</tr>
<tr>
<td>60 min</td>
<td>13 ± 1.5</td>
<td>13 ± 0.8</td>
<td>6.3 ± 0.4</td>
<td>6.3 ± 0.1</td>
</tr>
<tr>
<td><strong>Day 2</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 min</td>
<td>9 ± 1.0</td>
<td>10 ± 0.8</td>
<td>5.3 ± 0.3</td>
<td>5.1 ± 0.3</td>
</tr>
<tr>
<td>35 min</td>
<td>11 ± 1.4</td>
<td>13 ± 1.1*</td>
<td>5.7 ± 0.4</td>
<td>5.9 ± 0.2</td>
</tr>
<tr>
<td>60 min</td>
<td>11 ± 1.7</td>
<td>14 ± 1.1*</td>
<td>5.9 ± 0.4</td>
<td>6.6 ± 0.3*</td>
</tr>
<tr>
<td><strong>Day 3</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 min</td>
<td>9 ± 1.3</td>
<td>11 ± 1.1*</td>
<td>5.0 ± 0.3†</td>
<td>5.1 ± 0.2</td>
</tr>
<tr>
<td>35 min</td>
<td>11 ± 1.6</td>
<td>13 ± 1.1*</td>
<td>5.6 ± 0.4†</td>
<td>5.9 ± 0.3</td>
</tr>
<tr>
<td>60 min</td>
<td>11 ± 1.8</td>
<td>14 ± 1.2*</td>
<td>5.9 ± 0.4</td>
<td>6.0 ± 0.3</td>
</tr>
<tr>
<td><strong>Day 4</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 min</td>
<td>9 ± 1.2</td>
<td>12 ± 1.0*</td>
<td>5.1 ± 0.3†</td>
<td>5.1 ± 0.3</td>
</tr>
<tr>
<td>35 min</td>
<td>10 ± 1.5</td>
<td>12 ± 1.1*</td>
<td>5.6 ± 0.4†</td>
<td>5.8 ± 0.3</td>
</tr>
<tr>
<td>60 min</td>
<td>11 ± 1.7</td>
<td>14 ± 1.1*</td>
<td>5.9 ± 0.4</td>
<td>6.1 ± 0.3</td>
</tr>
<tr>
<td><strong>Day 5</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 min</td>
<td>9 ± 1.3</td>
<td>11 ± 1.1*</td>
<td>5.1 ± 0.3†</td>
<td>5.3 ± 0.3</td>
</tr>
<tr>
<td>35 min</td>
<td>10 ± 1.4</td>
<td>13 ± 1.1*</td>
<td>5.5 ± 0.4†</td>
<td>5.9 ± 0.2*</td>
</tr>
<tr>
<td>60 min</td>
<td>10 ± 1.4†</td>
<td>13 ± 1.0*</td>
<td>5.6 ± 0.4†</td>
<td>6.1 ± 0.3*</td>
</tr>
<tr>
<td><strong>Day 6</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 min</td>
<td>9 ± 1.1</td>
<td>11 ± 0.9*</td>
<td>5.1 ± 0.3†</td>
<td>5.4 ± 0.3</td>
</tr>
<tr>
<td>35 min</td>
<td>9 ± 1.2†</td>
<td>12 ± 1.2*</td>
<td>5.3 ± 0.3†</td>
<td>5.6 ± 0.2†</td>
</tr>
<tr>
<td>60 min</td>
<td>10 ± 1.3†</td>
<td>13 ± 1.4*</td>
<td>5.6 ± 0.3†</td>
<td>6.1 ± 0.4*</td>
</tr>
</tbody>
</table>

Values are means ± SE for 7 lean and 7 obese subjects. RPE, rating of perceived exertion; TS, thermal sensation. *Significant group difference at P < 0.05. †Significantly different from day 1 at P < 0.05.
Figure 4.1. Schematic of the experimental design for each trial. HR, heart rate; Tc, body core temperature; BP, blood pressure; BW, body weight; US, urine sample; Vol, volume of fluid ingested; RPE, rating of perceived exertion; TS, thermal sensation; V\textsubscript{o2}, oxygen consumption; R1, rest period 1; R2, rest period 2.
Figure 4.2.

Physical Activity Subscale:

Several times a week I exercise or play hard enough to breathe hard (to be out of breath)

I get exercise or do sports activities 3 or 4 times a week that make me breathe hard and last at least 30 minutes

I do lots of sports, dance, gym or other physical activities

Sports Competence Subscale:

Other people think that I am good at sports

I have good sports skills

I play sports well

Overall Averages:
Figure 4.2. Responses to the Physical Activity and Sports Competence subscales of the Physical Self Description Questionnaire on a 6-point true-false scale where 1 = “false”, 2 = “mostly false”, 3 = “more false than true”, 4 = “more true than false”, 5 = “mostly true”, and 6 = “true”. Only statements yielding significant effects are presented. Each subscale was comprised of 6 statements and the average of the 6 scores represents the overall average for that subscale. *Significant group difference at P < 0.05.
Figure 4.3.
Figure 4.3. Time course of mean $T_c$ response of 7 lean and 7 obese 9- to 12-yr-old boys during repeated exercise-heat bouts in the summer months. Exercise at 30% $V_{O_{2}\text{max}}$ alternated between a treadmill and bike for 3 20-min bouts interspersed with 5-min rest periods at 38°C and 50% rh. Values are means ± SE. Bas, Baseline; Rec, Recovery. A (lean boys $T_c$, day 1 and day 6) and B (lean boys $T_c$, all 6 days): *P < 0.001 between day 1 and day 6 for lean boys. C (obese boys $T_c$, day 1 and day 6) and D (obese boys $T_c$, all 6 days): ‡P < 0.001 between day 1 and day 6 for obese boys.
Figure 4.4.
Figure 4.4. Time course of mean HR response of 7 lean and 7 obese 9- to 12-yr-old boys during repeated exercise-heat bouts in the summer months. Exercise at 30% $\hat{V}o_{2\text{max}}$ alternated between a treadmill and bike for 3 20-min bouts interspersed with 5-min rest periods at 38°C and 50% rh. Values are means ± SE. Bas, Baseline; Rec, Recovery. A (lean boys HR, day 1 and day 6) and B (lean boys HR, all 6 days): *P < 0.001 between day 1 and day 6 for lean boys. C (obese boys HR, day 1 and day 6) and D (obese boys HR, all 6 days): No significant differences between days.
Chapter 5

CRITICAL ENVIRONMENTAL LIMITS FOR EXERCISING HEAT-ACCLIMATED LEAN AND OBESE BOYS

Introduction

Over a wide range of climatic conditions termed the “prescriptive zone” (84), $T_c$ is proportional to the work load (and therefore $M$) and independent of ambient conditions (142). Within the prescriptive zone, $T_c$ can equilibrate through physiological adjustments. As climatic heat stress increases, combinations of ambient temperatures and $P_a$ above this zone force $T_c$ upward, due to an imbalance between heat gain and heat loss, resulting in uncompensable heat stress. No study to date has determined these critical environmental conditions defining the upper limit of the prescriptive zone for a given $M$ in exercising children.

The approach used in the few studies investigating a child’s tolerance to exercise in the heat was to determine the time in a fixed environment in which a child was unable to continue exercising due to either subjective criterion (nausea, headache, etc) or measured physiological responses (rectal temperature $> 39^\circ$C or $> 90\%$ of maximum HR) (44; 61; 62). Exercising obese / overweight vs. lean children display no difference in heat tolerance but a greater physiological strain as indexed by a higher $T_c$ and HR (61; 62). Review of this data collectively gives an indication of the environmental conditions which might reduce a child’s exercise performance. From this information, organizations have developed position stands providing specific recommendations for setting restraints on activities at differing levels of climatic heat stress for exercising children (4; 7). However, each study employed an approximately $10^\circ$ increase in climatic conditions among trials, thus the environmental limit for uncompensable heat stress,
above which an imbalance between heat gain and heat loss forces $T_c$ upward, is difficult to determine. In addition, it is unclear if obese children exercising in the heat should have a different set of guidelines to follow compared to lean children.

The purpose of the present investigation was to determine for the first time, the critical environmental heat stress limits for exercising, heat-acclimated lean and obese 9- to 12-yr-old boys. It was hypothesized that during light-to-moderate intensity exercise in a warm environment, the critical environmental limits for heat-acclimated obese vs. lean 9- to 12-yr-old boys would be shifted downward on a psychrometric chart, towards lower $P_{crit}$. The $P_{crit}$ was identified by a continuous rise in $T_c$ and was defined as the critical ambient $P_a$ above which thermal balance could not be maintained during exercise.

**Methods**

**Subjects**

This study was approved by the Institutional Review Board of The Pennsylvania State University. Seven lean and 7 obese 9- to 12-yr-old boys volunteered to participate in this study. Lean and obese were defined as $\leq 20\%$ and $\geq 25\%$ body fat, respectively (86) as measured by whole body dual energy X-ray absorptiometry scan (model QDR 4500W, Hologic, Waltham, MA). Each subject and his parent / guardian were advised of all experimental procedures and associated risks before verbal assent was given by the child and a written informed consent was provided by the parent / guardian. All subjects were healthy, normotensive, and not taking any medications that could affect their cardiovascular or thermoregulatory responses. Preliminary screening included blood chemistry analysis (CHEM-24, complete blood count and lipid profile, Quest Diagnostics), and resting 12-lead electrocardiogram. During a maximal graded exercise
test on a treadmill, subjects began at a self-selected speed to elicit a HR of ~140- to 150-bpm at 0% grade, followed by an increase in slope of 2% until two of the following four criteria were met: 1) a plateau in $\dot{V}O_2$ defined as an increase of $\leq 2.0$ ml/kg/min; 2) a HR $> 195$ bpm; 3) a RER $> 1.0$; or 4) subjective indicators of fatigue such as hyperpnea, facial flushing, unsteady gait and refusal of the child to exercise further (56; 113). Subjects completed a physical exam during which a clinician determined pubertal status according to the criteria of Tanner (152). Subject characteristics are presented in Table 5.1.

**Experimental Design**

Before the experimental trials began, each subject completed six 70-min acclimation sessions (exercise + heat exposures) on separate days. Exercise at 30% $\dot{V}O_{2\text{max}}$ alternated between a treadmill (Precor USA C962) and cycle ergometer (Monark Ergomedic 818E) for three 20-min bouts interspersed with 5-min rests at 38°C, 50% relative humidity. During school recess and spontaneous playtime, children spend a majority of the time participating in light-to-moderate intensity activities (121); thus this exercise intensity was chosen because it reasonably simulates the workload typical of a child during spontaneous physical exertion. Experiments were conducted in the summer months, thus subjects were partially heat-acclimatized due to routine outdoor activities. Each subject completed 6 exercise in the heat bouts in order to attain further heat-acclimation from the partially heat-acclimatized state. BW was measured before and after each exposure and during rest periods and subjects were given water to maintain BW by replacing all water lost through sweat.

Following acclimation, subjects completed four separate tests on separate days in randomized order to determine the $P_{\text{crit}}$ for the upward inflection of $T_c$ at four distinct dry bulb
temperatures ($T_{db}$ = either 34, 36, 38 or 42°C). The $P_{cri}$ was identified by a continuous rise in $T_c$ and was defined as the critical ambient water vapor pressure above which thermal balance could not be maintained during exercise. All subjects in both groups completed the tests at $T_{db}$ = 34, 36, and 38°C. Seven lean and 5 obese subjects completed the tests at $T_{db}$ = 42°C. Three obese subjects also completed tests at $T_{db}$ = 28°C, in which all subjects were able to sustain exercise within the prescriptive zone at > 90% relative humidity. Therefore, trials at $T_{db}$ = 28°C were discontinued due to the inability to further increase the $P_a$. For all experimental trials the time between each scheduled test day was no more than 2 days. Subjects were encouraged to stay well-hydrated the day before each trial.

**Testing Procedures**

Subjects were asked to refrain from caffeine consumption on each day of the experiment and reported to the lab at least 2-h after a meal. After providing a urine sample, the subject was instrumented with a Polar® HR monitor, belt and pouch to attach the handheld recorder (CT2000) to the subject for continuous $T_c$ measurement and weighed (Seca 770, accuracy ± 50 g) wearing only shorts (all subsequent weights were taken wearing shorts only). Next the subject entered the preconditioned environmental chamber where skin thermocouples were attached.

During each test, the subject walked continuously on a treadmill, for up to 2.5 h at 30% $\dot{V}O_{2max}$ (for justification of exercise intensity see ‘Experimental Design’ section above). $T_{db}$ was held constant while $P_a$ increased approximately 1 Torr every 5-min, after a 30-min equilibration period at 9 Torr. There was no forced air movement in the programmable environmental chamber and air velocity measured near the active subject with an anemometer was 0.25 m/s. The experiment ended when the subject completed the protocol (i.e., a distinct
breakpoint in the Tc vs. time curve was evident), or if the Tc exceeded 39°C, the subject experienced adverse signs (nausea, dizziness, etc.), or if the subject desired to stop. After exiting the chamber at the conclusion of the experiment, a post-experiment urine sample was obtained.

**Measurements**

A minimum of 8-h before each test, subjects swallowed an ingestible temperature sensor (CorTemp, HQ Inc, Palmetto, Fla) for the measurement of Tc. The sensor is a single-use, pill-shaped electronic device that contains a telemetry system, a microbattery, and a quartz crystal whose frequency of vibration is linearly related to temperature. Each temperature sensor was calibrated by the manufacturer, which provides a serial number that is programmed into a handheld recorder (CT2000) ensuring an accuracy of 0.1°C. Each pill was used within 6 months from the date it was shipped by the manufacturer. Regarding the heat-acclimation trials, previous research has shown that during steady state exercise in a warm environment, the temperature and response time of the ingestible temperature sensor was in between that for rectal and esophageal (112).

Prior to the Pcrit trials, a pilot study was conducted to compare the agreement among methods for Tc measurement (esophageal, rectal and ingestible temperature sensor) utilizing the same dynamic protocol as in the present study. One male and 1 female subject walk on a treadmill at 3.8 mph in an environmental chamber where the Tdb was held constant at 36°C while the Pa was increased approximately 1 Torr every 5-min, after a 30-min equilibration period at 9 Torr. The root mean square deviation (RMSD) was calculated to compare the agreement among methods. At each minute, the RMSD between rectal and ingestible pill temperature (average RMSD = 0.24) was smaller than esophageal and rectal temperature (average RMSD = 0.32) and
the RMSD between esophageal and ingestible pill temperature (average RMSD = 0.16) was smaller than esophageal and rectal temperature. Therefore we conclude that the ingestible pill is a valid method for $T_c$ measurement under the present experimental conditions.

$T_{sk}$ was measured with copper-constantan thermocouples affixed to the skin at 4 sites: triceps ($T_{triceps}$), upper back ($T_{back}$), chest ($T_{chest}$), and thigh ($T_{thigh}$). All HR, $T_c$, $T_{sk}$, $T_{db}$, and wet bulb temperature ($T_{wb}$) data were measured continually through the protocol and stored as 1-min averages using computer software (Labview) in conjunction with a data-acquisition system (National Instruments, Austin, TX). BP by brachial auscultation (sphygmomanometry) was measured every 10-min. To ensure that each subject was working at the desired workload, expired air for the determination of $\dot{V}O_2$ was measured 30-min into the protocol for 5-min (TrueOne 2400 Metabolic Measurement System, ParvoMedics, Salt Lake City, UT). BW was measured before and after each trial.

Urine volume was measured with a graduated cylinders and urine color was determined by holding each specimen container next to a validated color scale (8) in a well-lit room. The eight-color scale ranges from very pale yellow (#1) to brownish green (#8). Urine osmolality (freezing point depression, Advanced DigiMatic Osmometer Model 3D2), and specific gravity (Refractometer, Atago A300CL) were determined in triplicate.

**Determination of Critical Water Vapor Pressure**

The methods used to determine the $P_{crit}$ have been previously described (69; 70; 76). The $T_c$, HR, $T_{sk}$ and $P_a$ data from a typical $P_{crit}$ test are illustrated in Figure 5.1. Briefly, as subjects walked during the 30-min equilibration period, $T_c$ increased and then began to plateau by approximately 40-min. At some point, the rising $P_a$ pushed $T_c$ past the prescriptive zone of
thermal balance as evidenced by a distinct breakpoint in the $T_c$ vs. time curve where $T_c$ began to rise again. To determine this inflection point, first a line was drawn from minute 30 between data points to denote the equilibrium slope. When the $T_c$ vs. time curve exhibited an increase in slope from the equilibrium slope, a second line was drawn from the point of departure of $T_c$ from the first line. Based on pilot testing demonstrating that there is a 2-min lag in the ingestible temperature sensor response time compared to esophageal temperature, the $P_a$ 2-min before the upward inflection point (the point at which the second line deviated from the first line) was defined as the $P_{crit}$ in the present study. Approximately 10 to 15-min prior to the $T_c$ inflection point, an upward rise in HR (69; 70; 74; 76) was evident in all tests.

To test the reliability of the $P_{crit}$ data, tests were repeated by 8 different subjects on a separate day. Two different subjects completed repeat trials at each of the $T_{db} = 34$ (1 lean and 1 obese subject), 36 (1 lean and 1 obese subject), 38 (2 obese subjects), and 42 (1 lean and 1 obese subject) °C. In order to account for the repeated $P_{crit}$ tests, the time points at which each inflection point occurred were compared and a test-retest correlation was calculated, resulting in a correlation coefficient ($r$) of 0.99, with a slope of 0.97 (NS vs. 1.0) and an intercept of 3.66 (NS vs. 0).

**Subjective Ratings**

During the preliminary screening, the Physical Activity and Sports Competence subscales of the Physical Self Description Questionnaire which has been validated for use in adolescents (91) was completed to subjectively determine how “active” each subject perceived himself to be on a daily / weekly basis. Each item is a simple declarative statement, all positively worded, and subjects respond on a 6-point true-false response scale where 1 = “false”, 2 = “mostly false”, 3 =
“more false than true”, 4 = “more true than false”, 5 = “mostly true”, and 6 = “true”. The statements which the subjects responded to were, “Several times a week I exercise or play hard enough to breathe hard (to be out of breath)”, “Other people think that I am good at sports”, “I often do exercise or activities that make me breathe hard”, “I am good at most sports”, “I get exercise or do sports activities 3 or 4 times a week that make me breathe hard and last at least 30 minutes”, “I do physically active things (like jogging, dancing, bicycling, aerobics, gym or swimming) at least three times a week”, “I have good sports skills”, “I do lots of sports, dance, gym or other physical activities”, “I am better at sports than most of my friends”, “I do sports, exercise, dance or other activities almost every other day”, and “I play sports well”. During each experiment, RPE (Borg scale (26)) and TS, using a 0-8 scale in which 0 = unbearable cold, 4 = thermoneutral, and 8 = unbearably hot (174)) were measured every 10-min. After the completion of each experiment, subjects completed the modified version of the Physical Activity Enjoyment Scale which has been validated for use in adolescents (107) to assess how well the subject tolerated the exercise in the heat bouts. The scale consists of both positively and negatively worded statements scored on a 5-point scale where, 1 = “disagree a lot”, 2 = “disagree a little”, 3 = “neither agree or disagree”, 4 = “agree a little”, and 5 = “agree a lot”. Subjects were asked to think about the exercise they just completed and responded to the following statements, “I feel as though I would rather be doing something else”, “it gives me a strong feeling of success”, “it’s not at all interesting”, “it frustrates me”, “it’s very exciting”, “I get something out of it”, “my body feels good”, “it’s very pleasant”, “it makes me depressed”, “it gives me energy”, “it’s not fun at all”, “I find it fun”, “I dislike it”, “I feel bored”, and “I enjoy it”.
Calculations

For all experimental trials, subjects wore shorts, socks and sneakers and therefore, no clothing corrections were made for this “semi-nude” state. \( A_D \) was estimated according to Dubois and Dubois (45) and \( A_D / \text{mass} \) was calculated. A weighted \( \tilde{T}_{\text{sk}} (^\circ C) \) was calculated as

\[
\tilde{T}_{\text{sk}} = 0.3 \cdot T_{\text{chest}} + 0.3 \cdot T_{\text{back}} + 0.2 \cdot T_{\text{triceps}} + 0.2 \cdot T_{\text{thigh}}.
\]

Sweating rate was calculated from the net change in BW corrected for fluid consumption and urine excreted. Respiratory losses were considered negligible. MAP (torr) was calculated as

\[
\text{MAP} = (1/3) \cdot \text{pulse pressure} + \text{diastolic BP}.
\]

The WBGT; °C was calculated as

\[
\text{WBGT} = 0.3 \cdot T_{\text{db}} + 0.7 \cdot T_{\text{wb}}.
\]

\( M (W/m^2) \) was calculated from the RER (unitless), \( \dot{V}O_2 \) (l/min) and \( A_D \) (m²) as

\[
M = 352 \cdot (0.23 \cdot \text{RER} + 0.77) \cdot \dot{V}O_2/A_D.
\]

External work (W; W/m²) was calculated from BW (kg), walking velocity (\( v_w \); m/min), fractional grade of the treadmill (\( f_g \)) and \( A_D \) as

\[
W = 0.163 \cdot \text{BW} \cdot v_w \cdot f_g/A_D.
\]

Net metabolic heat production (\( M_{\text{net}} \); W/m²) was calculated as \( M-W \).

Radiative and convective (\( R + C \>; W/m²²) dry heat exchange was calculated as

\[
R + C = h_{r+c} \cdot (T_{\text{db}} - T_{\text{sk}})
\]

where \( h_{r+c} \) (W·m⁻²·°C⁻¹) is the combined radiative and convective heat transfer coefficient and \( T_{\text{db}} - T_{\text{sk}} \) denotes the temperature gradient between ambient air and the skin. For each subject, \( h_{r+c} \) was calculated as

\[
h_{r+c} = 6.5 \cdot (\text{treadmill speed; m/s})^{0.39} + 4.7
\]
where 6.5 · (treadmill speed; m/s)$^{0.39}$ is the convective coefficient for treadmill walking (111) and 4.7 is the radiative coefficient for indoor environments.

Heat storage (S; W/m$^2$) was calculated as

$$S = \frac{\Delta T_b}{\Delta t} \cdot (0.97 \text{ W·h·kg}^{-1}·\text{°C}^{-1}) \cdot (BW/AD)$$

where $\Delta T_b/\Delta t$ is the change in mean body temperature ($\Delta T_b$; °C) measured over time ($\Delta t$; h) from minute 30 until a distinct breakpoint in the $T_c$ vs. time curve was evident, and 0.97 W·h·kg$^{-1}·$°C$^{-1}$ is the specific heat of the body.

The $\Delta T_b$ was calculated as

$$\Delta T_b = (0.9 \cdot T_c + 0.1 \cdot T_{sk}) \text{ at critical point} - (0.9 \cdot T_c + 0.1 \cdot T_{sk}) \text{ at minute 30}.$$ 

The heat balance equation was then used to solve for the evaporative heat loss required to match heat production ($E_{req}; \text{ W/m}^2$)

$$E_{req} = (M-W) \pm (R+C) - S.$$ 

The skin evaporative capacity ($E_{sk}; \text{ W/m}^2$) for each trial was determined by multiplying the sweating rate by the specific heat of vaporization, 0.68 W·h·g$^{-1}$.

The maximal evaporative capacity of the environment ($E_{max}; \text{ W/m}^2$) was calculated as

$$E_{max} = 18.4 \text{ W·m}^{-2}·\text{Torr}^{-1} \cdot v^{0.6} \cdot (P_{s,sk} - P_a)$$

where 18.4 W·m$^{-2}·$Torr$^{-1}$ is the effective evaporative coefficient for heat-acclimatized males (21), air velocity ($v; \text{ m·s}^{-1}$) was equal to 0.25 for this study and $P_{s,sk} - P_a$ (torr) is the gradient between saturated $P_a$ of the skin (determined by Antoine’s equation (116)) and the air at the critical point.

Skin wettedness ($w; \%$) was calculated as $E_{req} / E_{max}$. 
Statistical Analyses

A repeated measures analysis of covariance by SAS PROC MIXED was used to analyze the variables that changed throughout conditions. This linear mixed model took into account the correlated nature of the repeated measures. Group was treated as a fixed effect and subjects were treated as random effects. The independent variables were group and $T_{db}$ and the dependent variable was the unknown critical environmental parameter. For the physiological data measured over different time points, group, time and $T_{db}$ were the independent variables. When making multiple comparisons, Bonferroni adjustments were used. Results were considered significant at $P < 0.05$.

During exercise in the heat, whereas metabolic heat production is a reflection of absolute intensity, heat loss mechanisms are a function of relative intensity. Thus, heat storage and the subsequent rise in $T_c$ is dependent to some degree upon both absolute and relative intensities. In the present study, work at the same relative intensity was the logical choice in order to investigate differences in heat loss mechanisms between lean and obese boys. However, to investigate the impact of absolute vs. relative intensity, 4 lean and 3 obese subjects repeated the first heat-acclimation trial which matched the absolute and relative workloads of the lean and obese groups (i.e. decreasing the workload for the lean group to match the obese group and increasing the workload for the obese group to match the lean group). The time between the completion of the last experimental trial ($4^{th} P_{crit}$ trial) and the repeat heat-acclimation trial was $> 2$ months. The Bland-Altman approach to measuring agreements for repeated measures was used to determine the agreement of $T_c$ between the first (relative exercise intensity) and repeated (absolute exercise intensity) trials using $\pm 0.3^\circ C$ as the physiological threshold for assessment. This threshold takes into account the anticipated standard deviation for $T_c$ measurement in boys.
of this age (17). The mean difference between the two trials was 0.01°C and the standard deviation of the difference between the two trials was 0.08°C. The 95% limits of agreement were -0.1503 to 0.1621. Therefore, when matched for absolute and relative exercise intensity, the difference in $T_c$ was within acceptable limits and considered marginal under practical consideration. This suggests that other factors independent of exercise intensity contribute to significant differences observed in the present study.

**Results**

Compared to lean subjects, obese subjects perceived themselves to be significantly less active (P < 0.03) as determined by significantly lower subjective ratings to the following questions: “Several times a week I exercise or play hard enough to breath hard (to be out of breath)” (lean vs. obese = 6 ± 0.2 vs. 4 ± 0.5, P < 0.03), “I get exercise or do sports activities 3 or 4 times a week that make me breath hard and last at least 30 minutes” (lean vs. obese = 5 ± 0.2 vs. 4 ± 1.4, P < 0.02), “I do lots of sports, dance, gym or other physical activities” (lean vs. obese = 6 ± 0 vs. 4 ± 0.6, P < 0.003). In addition, obese subjects reported feeling significantly less competent playing sports (P < 0.03) as indicated by significantly lower subjective ratings to the following questions: “Other people think that I am good at sports” (lean vs. obese = 6 ± 0.2 vs. 4 ± 0.6, P < 0.008), “I have good sports skills” (lean vs. obese = 6 ± 0.2 vs. 4 ± 0.5, P < 0.02), “I play sports well” (lean vs. obese = 6 ± 0.2 vs. 4 ± 0.6, P < 0.03).

Six lean and 2 obese subjects were classified as pre-pubertal (Tanner stage 1), 5 obese subjects were classified as mid-pubertal (Tanner stage 2-4) and 1 lean subject was classified as late-pubertal (Tanner stage 5). As expected, obese subjects weighed more, had a higher $A_D$, a lower $A_D/\text{mass ratio}$, higher percent body fat, and a lower $\bar{V}o_2\text{max}$ (all P < 0.05; Table 5.1).
Body fatness ranged from 14 to 20% in the lean subjects and from 28 to 45% in the obese subjects. There were no significant differences between groups in baseline $T_c$.

Compared to lean subjects, obese subjects had significantly lower $M$ (lean vs. obese = 200 ± 3 vs. 164 ± 4 W/m² at $T_{db} = 34^\circ$C; 196 ± 9 vs. 172 ± 4 W/m² at $T_{db} = 36^\circ$C; 202 ± 8 vs. 167 ± 10 W/m² at $T_{db} = 38^\circ$C; 217 ± 4 vs. 169 ± 4 W/m² at $T_{db} = 42^\circ$C; all $P < 0.001$), $W$ performed (lean vs. obese = 7 ± 0.9 vs. 4 ± 0.2 W/m² for all trials; all $P < 0.003$), $M_{\text{net}}$, $E_{\text{req}}$, and $w$ during exercise at 30% $\dot{V}O_2\text{max}$ in each critical environment (all $P < 0.03$; Table 5.2). The measured exercise intensity ranged from 30.2 ± 0.6% to 34.5 ± 0.5% for the lean subjects and 30.5 ± 0.5% to 34.3 ± 0.4% for the obese subjects across trials ($P > 0.05$). There was no difference between groups in $R+C$, $S$, (both Table 5.2) or $\Delta T_b$ (lean vs. obese = 0.61 ± 0.10 vs. 0.48 ± 0.07°C at $T_{db} = 34^\circ$C; 0.52 ± 0.10 vs. 0.34 ± 0.06°C at $T_{db} = 36^\circ$C; 0.46 ± 0.06 vs. 0.43 ± 0.07°C at $T_{db} = 38^\circ$C; 0.51 ± 0.06 vs. 0.30 ± 0.07°C at $T_{db} = 42^\circ$C) in each critical environment. Compared to lean subjects, $E_{\text{max}}$ was consistently significantly lower for the obese subjects in each critical environment (lean vs. obese = 100 ± 4 vs. 115 ± 4 W/m² at $T_{db} = 34^\circ$C; 127 ± 4 vs. 142 ± 8 W/m² at $T_{db} = 36^\circ$C; 149 ± 3 vs. 165 ± 7 W/m² at $T_{db} = 38^\circ$C; 174 ± 6 vs. 182 ± 9 W/m² at $T_{db} = 42^\circ$C; all $P < 0.04$). Obese subjects had a significantly lower relative (ml·m⁻²·h⁻¹) but not absolute (ml·h⁻¹) mean sweating rate which translated into a significantly lower $E_{sk}$ compared to lean subjects (both $P < 0.04$; Table 5.2 and 5.3).

Obese subjects consistently had significantly lower critical environmental limits and a significantly higher ($P_{s,sk} - P_a$) in each warm environment compared to lean subjects (all $P < 0.04$; Table 5.4). These environmental thresholds are plotted on a standard psychrometric chart in Figure 5.2. The WBGT was significantly lower in each critical environment for the obese vs. lean subjects ($P < 0.04$). In each warm environment, at the $P_{\text{crit}}$ there were no significant
differences between groups in $T_c$ or $T_{sk}$. No pre or post urine variable was significantly different between groups. Likewise, there were no significant differences between groups in MAP at each time point across all $T_{db}$.

Subjective responses during exercise at each $T_{db}$ are presented in Table 5.5. At the beginning of the exercise bout (10 min), TS and RPE were significantly higher in the obese vs. lean subjects at $T_{db} = 36, 38$ and $42^\circ$C (all $P < 0.05$). At min 50 and the critical environment, obese subjects continued to rate perceived exertion and TS significantly higher compared to lean subjects in all conditions (all $P < 0.05$). After the completion of each experiment, subjective responses to each question of the modified version of the Physical Activity Enjoyment Scale were not significantly different between groups for each trial.

**Discussion**

The main finding from this study is that during light-to-moderate exercise at a similar relative intensity (30% $\dot{V}O_{2\text{max}}$) in a warm environment, the critical environment limits for heat-acclimated obese vs. lean 9- to 12-yr old children are shifted downward on a psychrometric chart, toward a lower $P_{crit}$. Above these limits, thermal balance cannot be maintained, and a continuous rise in $T_c$ is evident.

**Psychrometric Limits**

For exercising children, position stands (4; 7) recommending restricting activities at increasing levels of heat stress are based upon studies which determined the maximal tolerated time in a fixed environment (44; 61; 62). The present study empirically defined critical environmental limits of uncompensable heat stress for 9- to 12-yr-old heat-acclimated boys at a
fixed relative exercise intensity based solely on thermal balance. These thermal limits are commonly displayed as lines on a psychrometric chart, which separate environmental zones of compensable and uncompensable heat stress (Figure 5.2). Above these limit lines, an excessive rise in $T_c$ is predicted as thermal equilibrium cannot be maintained. However, several points must be emphasized: 1) these limits apply only to situations where exercise intensity is low to moderate (approximately 30% $\dot{V}o_2\text{max}$); 2) these limits are expanded by heat-acclimation and are likely to be lower for unacclimated boys (76); and 3) it is difficult to discern how a radiant heat load and/or wind might impact these environmental thresholds. Thus, the recommendations presented should be used as an approximate guide rather than a strict rule.

The data presented are mean critical vapor pressures. However, in order to provide “safe” limits for 95% of the population, values 2 standard deviations below the mean would be appropriate. Since relative humidity values are more easily accessible and understood, Table 5.6 presents temperature and protective relative humidity combinations for 95% of the population (2 standard deviations below the mean). Another thermal index used to assess heat stress is WBGT, which was the focus of the American Academy of Pediatrics position stand (4). Critical WBGT values are presented in Table 5.4. However, the average of all individual critical WBGT values from the 4 trials which results in one overall WBGT value per group, 2 standard deviations below the mean, would be most user friendly. Therefore, protective WBGT values for 95% of the population, 2 standard deviations below the mean are lean = 30°C and obese = 29°C, which is in agreement with the recommendations set forth by the American Academy of Pediatrics.

In response to an exercise-heat stress, heat-loss mechanisms attempt to defend $T_c$ by increasing skin blood flow for convective heat transfer from core to periphery and sweating rate
to enhance evaporative heat loss. The efficiency of these heat-dissipation mechanisms are
governed by multiple factors including environmental conditions, $A_D / \text{mass ratio}$, hydration
status, body fat and $M$. Havenith and Middendorp (60) found that in adults the percentage of
body fat and the $A_D / \text{mass ratio}$ had the greatest influence on $T_c$ and heat storage during exercise
in warm / humid and hot / dry conditions. It is likely that not one but a combination of several
factors contributed to the attenuated $P_{crit}$ values in the obese vs. lean boys in the present study.

When environmental temperature is close to or above $T_{sk}$, dry heat exchange via radiation
and convection, which is dependent upon the gradient between skin and $T_{dbs}$ is minimal. In this
environment, heat loss at a given $M$ occurs via evaporation of sweat. However, in high vapor
pressure environments, evaporative cooling is limited due to the decreased $P_a$ gradient between
the saturated skin and the air. In the present study, dry heat exchange was not significantly
different between groups. In these warm/humid environments, the evaporation of sweat, which
was the primary means of heat dissipation, likely depends on the optimal sweating rate for a
given unit of metabolic heat production and $A_D$. Considering the time spent in less stressful
environments earlier in the exposures and the inverse relationship between $A_D$ and sweat gland
density (18), the lower sweating rates per $A_D$ in the obese vs. lean subjects might have been
insufficient to maintain the evaporative heat loss necessary to match metabolic heat production.
However, sweating rate is not synonymous with evaporation and at the critical point at each $T_{db}$,
the estimated $w$ values were $> 1.0$ for both groups, suggesting dripped sweat which does not cool
the skin. The calculated sweat rate is averaged over a long time period and the true sweating rate
in the critical environment is unknown.

The metabolic heat generated during exercise is proportional to the active muscle mass
(related to body mass) whereas the capacity for heat exchange with the environment is a function
of $A_D$. A larger individual has a greater $A_D$, but a smaller individual has a greater $A_D / \text{mass}$ ratio. The larger individual, due to their smaller $A_D / \text{mass}$, loses metabolic heat generated during exercise at a slower rate than a smaller person (127). Since adipose tissue has a lower specific heat of stored lipid and less water, less heat can be stored in adipose vs. lean tissue before a rise in the tissue temperature is observed (30). Haymes et al. (62) found no difference in heat storage, but a greater rise in $T_c$ in obese vs. lean partially heat-acclimated 9- to 12-yr-old boys during exercise in the heat at the same absolute intensity. The earlier inflection in $T_c$ in obese subjects with rising $P_a$ despite similar $S$ in both groups across all trials in the present study is in agreement with previous findings in this age group.

Forearm blood flow during exercise in the heat is lower in obese compared to lean adults (162) which could impede the convection of heat by blood from core to the periphery. Although no study has investigated the skin blood flow response during exercise in the heat in obese vs. lean children, nor was it measured in the present study, this could be another physiological liability contributing to the significantly lower $P_{crit}$ values in the obese compared to lean boys in the present study.

**Subjective Responses**

Several RPE scales have been developed specifically for children to quantify their perceived physical effort during exercise (48). However, Borg’s established 6-20 RPE scale was used in the present study because: 1) it is both valid and reliable for use with children 9 yrs and older (13; 87); 2) obese children can rate their perceived exercise intensity both accurately and consistently (20); and 3) using Borg’s scale with children exercising in the heat can serve as a common denominator for comparison with adults in future studies. Surprisingly, very few
studies have compared effort perception during exercise between lean and obese children, with no studies conducted in the heat. Ward et al. (166) found a higher perception of effort, by 1.5 to 2 RPE units in obese compared to lean children during exercise. The present study indicates that an obese child’s perception of effort during exercise in the heat is significantly greater throughout the entire bout (some protocols lasting 2.5 hrs) compared to their lean counterparts. It is difficult to ascertain factors which may have contributed to the higher RPE values (i.e. increases in ventilation, M, HR, Tsk, Tc, acidity, etc.) and to differentiate the magnitude of their impact. It is interesting to note that the obese children had significantly higher RPE values 10-min into the exercise bout. The significantly higher effort perception during exercise in the heat in obese vs. lean children in the present study, suggests that obese children may require enhanced encouragement and support while exercising in the heat.

**Protocol**

The protocol utilized in the present study evolved from one first developed by Belding and Kamon (21). Their time-intensive method determined P<sub>crit</sub> values for heat-acclimatized men exercising at different intensities and air speeds (up to 10 separate exposures in a different environment, either semi-nude or clothed) at T<sub>db</sub> = 36°C while P<sub>a</sub> was held constant for the full 2-h exposure. The most stressful ambient conditions in which a continuous rise in T<sub>c</sub> was not observed was classified as the upper limit of thermal balance for that condition. As opposed to separate test in each environment, Kamon and Avellini later refined this protocol by defining P<sub>crit</sub> values at several T<sub>db</sub>’s for heat-acclimated women by increasing P<sub>a</sub> throughout each test (69). Subsequent studies determined critical environmental limits for lightly (70) and heavier (74) clothed heat-acclimated and lightly clothed (76) unacclimated men and women. The present
study extends these critical environmental heat stress limits to a novel population of heat-acclimated children. Although the present study did not directly compare children and adults, it is interesting to consider how these critical environmental limits might differ between boys vs. men. The critical environment at $T_{db} = 36^\circ$C for heat-acclimated semi-nude lean boys in the present study (mean ± SD = 29.6 ± 1.5 torr) is substantially lower than that of semi-nude heat-acclimatized men (21) (34 torr) exercising at a similar $M_{net}$ (approximately 190 W/m²). However, the air movement differed between studies (boys vs. men = 0.25 vs. 0.83 m/sec). These critical environmental limits at $T_{db} = 36^\circ$C in the present study more closely resemble those determined for lightly clothed heat-acclimated men (mean ± SD = 30.6 ± 1.4 (70)) exercising at a similar $M_{net}$ (approximately 190 W/m²). However, again the air movement differed between studies (boys vs. men = 0.25 vs. 1 m/sec). Theoretically, compared to an adult during exercise in the heat, a child’s lower sweating rate per unit $A_D$ which could diminish the capacity for evaporative heat loss, lower cardiac output at a given $V_o2$ which could limit the transfer of heat from core to the periphery via blood flow and greater $A_D$/ mass ratio which might result in faster heat absorption, could place them at a thermoregulatory disadvantage (49). However, as reviewed by Rowland, recent studies directly comparing physiological and thermoregulatory responses to exercise in the heat between children and adults fail to show thermoregulatory differences (139). More research is needed to elucidate if children are at an increased risk for heat-related illnesses compared to adults.

In summary, during light-to-moderate intensity exercise in a warm environment heat-acclimated obese compared to lean 9- to 12-yr-old boys display attenuated critical environmental limits, above which a continuous rise in $T_c$ is observed. This suggests that separate guidelines
which set restraints on activities at differing levels of climatic heat stress should be tailored to obese and lean children exercising in the heat.
Table 5.1. Subject characteristics by group

<table>
<thead>
<tr>
<th></th>
<th>Lean Boys</th>
<th>Obese Boys</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Age, yr</td>
<td>11 ± 0.3</td>
<td>11 ± 0.2</td>
</tr>
<tr>
<td>Height, cm</td>
<td>152 ± 2</td>
<td>155 ± 1</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>42 ± 2</td>
<td>54 ± 4*</td>
</tr>
<tr>
<td>$A_D$, m$^2$</td>
<td>1.33 ± 0.03</td>
<td>1.50 ± 0.05*</td>
</tr>
<tr>
<td>$A_D$/mass, m$^2$/kg</td>
<td>0.032 ± 0.001</td>
<td>0.028 ± 0.001*</td>
</tr>
<tr>
<td>Body fat, %</td>
<td>18 ± 1</td>
<td>33 ± 2*</td>
</tr>
<tr>
<td>Lean body mass, kg</td>
<td>32 ± 1</td>
<td>33 ± 1</td>
</tr>
<tr>
<td>$V_{O_2^{max}}$, ml·kg$^{-1}$·min$^{-1}$</td>
<td>49 ± 1</td>
<td>37 ± 2*</td>
</tr>
<tr>
<td>$V_{O_2^{max}}$, L/min$^{-1}$</td>
<td>2.1 ± 0.1</td>
<td>2.0 ± 0.1</td>
</tr>
</tbody>
</table>

Values are means ± SE. $A_D$, DuBois surface area; $V_{O_2^{max}}$, maximal aerobic capacity.
*Significantly different from lean boys, P < 0.05.
Table 5.2. Calculated heat balance variables in each critical environment

<table>
<thead>
<tr>
<th></th>
<th>M&lt;sub&gt;net&lt;/sub&gt;, W/m&lt;sup&gt;2&lt;/sup&gt;</th>
<th>R+C, W/m&lt;sup&gt;2&lt;/sup&gt;</th>
<th>S, W/m&lt;sup&gt;2&lt;/sup&gt;</th>
<th>E&lt;sub&gt;sk&lt;/sub&gt;, W/m&lt;sup&gt;2&lt;/sup&gt;</th>
<th>E&lt;sub&gt;req&lt;/sub&gt;, W/m&lt;sup&gt;2&lt;/sup&gt;</th>
<th>w, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lean</td>
<td>Obese</td>
<td>Lean</td>
<td>Obese</td>
<td>Lean</td>
<td>Obese</td>
<td>Lean</td>
</tr>
<tr>
<td>34°C</td>
<td>192 ± 3</td>
<td>161 ± 4*</td>
<td>-29 ± 2</td>
<td>-23 ± 2</td>
<td>12 ± 2</td>
<td>10 ± 1</td>
</tr>
<tr>
<td>36°C</td>
<td>189 ± 10</td>
<td>168 ± 3*</td>
<td>-5 ± 3</td>
<td>-2 ± 3</td>
<td>14 ± 2</td>
<td>9 ± 1</td>
</tr>
<tr>
<td>38°C</td>
<td>195 ± 8</td>
<td>163 ± 4*</td>
<td>16 ± 2</td>
<td>20 ± 2</td>
<td>14 ± 1</td>
<td>16 ± 3</td>
</tr>
<tr>
<td>42°C</td>
<td>209 ± 4</td>
<td>165 ± 4*</td>
<td>60 ± 3</td>
<td>56 ± 3</td>
<td>23 ± 2</td>
<td>15 ± 2</td>
</tr>
</tbody>
</table>

Values are means ± SE for 7 lean and 7 obese subjects at 34, 36 and 38°C and 7 lean and 5 obese subjects at 42°C. M<sub>net</sub>, net metabolic heat production; R+C, dry heat exchange via radiation and convection; S, heat storage; E<sub>sk</sub>, evaporative cooling from the skin; E<sub>req</sub>, required evaporation to maintain heat balance; w, % skin wettedness, calculated as E<sub>req</sub>/E<sub>max</sub>. *Significant group difference at P < 0.05.
Table 5.3. Sweating rate

<table>
<thead>
<tr>
<th></th>
<th>Sweating Rate, ml·h^{-1}</th>
<th>Sweating Rate, ml·m^{-2}·h^{-1}</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lean</td>
<td>Obese</td>
</tr>
<tr>
<td>34°C</td>
<td>341 ± 27</td>
<td>260 ± 38</td>
</tr>
<tr>
<td>36°C</td>
<td>371 ± 35</td>
<td>303 ± 44</td>
</tr>
<tr>
<td>38°C</td>
<td>442 ± 28</td>
<td>390 ± 43</td>
</tr>
<tr>
<td>42°C</td>
<td>477 ± 71</td>
<td>393 ± 21</td>
</tr>
</tbody>
</table>

Values are means ± SE for 7 lean and 7 obese subjects at 34, 36 and 38°C and 7 lean and 5 obese subjects at 42°C. *Significant group difference at P < 0.05.
Table 5.4. Results from the determination of critical environmental limits and water vapor pressure gradients

<table>
<thead>
<tr>
<th></th>
<th>P&lt;sub&gt;crit&lt;/sub&gt;, torr</th>
<th>T&lt;sub&gt;wbcrit&lt;/sub&gt;, °C</th>
<th>RH&lt;sub&gt;crit&lt;/sub&gt;, %</th>
<th>WBGT&lt;sub&gt;crit&lt;/sub&gt;, °C</th>
<th>P&lt;sub&gt;s,sk - P&lt;sub&gt;a&lt;/sub&gt;&lt;/sub&gt;, torr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lean</td>
<td>Obese</td>
<td>Lean</td>
<td>Obese</td>
<td>Lean</td>
<td>Obese</td>
</tr>
<tr>
<td>34°C</td>
<td>32.9 ± 0.7</td>
<td>30.3 ± 0.8*</td>
<td>31.2 ± 0.3</td>
<td>30.1 ± 0.3*</td>
<td>82 ± 2</td>
</tr>
<tr>
<td>36°C</td>
<td>29.6 ± 0.6</td>
<td>27.2 ± 0.9*</td>
<td>30.3 ± 0.3</td>
<td>29.2 ± 0.4*</td>
<td>66 ± 1</td>
</tr>
<tr>
<td>38°C</td>
<td>27.8 ± 0.6</td>
<td>24.7 ± 0.9*</td>
<td>29.9 ± 0.3</td>
<td>28.5 ± 0.4*</td>
<td>56 ± 1</td>
</tr>
<tr>
<td>42°C</td>
<td>25.5 ± 0.7</td>
<td>24.5 ± 1.5*</td>
<td>29.7 ± 0.3</td>
<td>29.3 ± 0.7*</td>
<td>41 ± 1</td>
</tr>
</tbody>
</table>

Values are means ± SE for 7 lean and 7 obese subjects at 34, 36 and 38°C and 7 lean and 5 obese subjects at 42°C. P<sub>crit</sub>, the critical water vapor pressure; T<sub>wbcrit</sub>, critical wet bulb temperature; RH<sub>crit</sub>, critical relative humidity; WBGT<sub>crit</sub>, critical wet bulb globe temperature, P<sub>s,sk - P<sub>a</sub></sub>, the gradient between saturated water vapor pressure of the skin and the air at the critical point. *Significant group difference at P < 0.04.
Table 5.5. Subjective responses

<table>
<thead>
<tr>
<th></th>
<th>RPE</th>
<th>TS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lean</td>
<td>Obese</td>
</tr>
<tr>
<td><strong>34°C</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 min</td>
<td>9 ± 1.2</td>
<td>11 ± 1.3*</td>
</tr>
<tr>
<td>50 min</td>
<td>10 ± 1.2</td>
<td>13 ± 1.3*</td>
</tr>
<tr>
<td>Critical</td>
<td>13 ± 2.0</td>
<td>16 ± 1.4*</td>
</tr>
<tr>
<td><strong>36°C</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 min</td>
<td>9 ± 1.1</td>
<td>11 ± 1.4*</td>
</tr>
<tr>
<td>50 min</td>
<td>11 ± 1.5</td>
<td>14 ± 1.4*</td>
</tr>
<tr>
<td>Critical</td>
<td>13 ± 2.0</td>
<td>15 ± 1.8*</td>
</tr>
<tr>
<td><strong>38°C</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 min</td>
<td>9 ± 1.2</td>
<td>11 ± 1.5*</td>
</tr>
<tr>
<td>50 min</td>
<td>11 ± 1.7</td>
<td>13 ± 1.6*</td>
</tr>
<tr>
<td>Critical</td>
<td>13 ± 2.0</td>
<td>15 ± 1.5*</td>
</tr>
<tr>
<td><strong>42°C</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 min</td>
<td>9 ± 1.3</td>
<td>11 ± 1.8*</td>
</tr>
<tr>
<td>50 min</td>
<td>10 ± 1.5</td>
<td>14 ± 2.2*</td>
</tr>
<tr>
<td>Critical</td>
<td>12 ± 1.8</td>
<td>16 ± 2.5*</td>
</tr>
</tbody>
</table>

Values are means ± SE for 7 lean and 7 obese subjects at 34, 36 and 38°C and 7 lean and 5 obese subjects at 42°C. RPE, rating of perceived exertion; TS, thermal sensation; Critical, critical environmental threshold. *Significant group difference at P < 0.05.
Table 5.6. Protective relative humidity

<table>
<thead>
<tr>
<th></th>
<th>Protective RH %</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Lean</td>
<td>Obese</td>
<td></td>
</tr>
<tr>
<td>34°C</td>
<td>72</td>
<td>66</td>
</tr>
<tr>
<td>36°C</td>
<td>60</td>
<td>49</td>
</tr>
<tr>
<td>38°C</td>
<td>50</td>
<td>40</td>
</tr>
<tr>
<td>42°C</td>
<td>35</td>
<td>30</td>
</tr>
</tbody>
</table>

Values are means ± SE for 7 lean and 7 obese subjects at 34, 36 and 38°C and 7 lean and 5 obese subjects at 42°C. Protective RH, protective relative humidity for 95% of the population, 2 standard deviations below the mean.
Figure 5.1.

![Graph showing Tc (degree C) and HR (bpm) over time, with Tc inflection point at Pcrit = 27 torr.](image)

- Tc
- HR
- Pa
- Tsk

Pcrit = 27 torr
Figure 5.1. A representative critical water vapor pressure ($P_{\text{crit}}$) test illustrating the typical time course of body core temperature ($T_c$), heart rate (HR), and mean skin temperature ($T_{sk}$) responses to exercise and rising ambient water vapor pressure ($P_a$). Subjects walk continuously on a treadmill at 30% $\dot{V}O_{2\text{max}}$ at a constant dry bulb (38°C in this test). After a 30-min equilibration period at 9 Torr, $P_a$ increases approximately 1 torr every 5-min. $T_c$ which is proportional to the work load and independent of ambient conditions increases to a steady state. Upon reaching a critical environment, $T_c$ begins to rise again and a distinct breakpoint in the $T_c$ vs. time curve is evident. Pilot testing determined that there is a 2-min lag in the ingestible temperature sensor response time compared to esophageal temperature. Therefore, the $P_a$ 2-min before the inflection point was defined as the $P_{\text{crit}}$, which was 27 torr in this example. Approximately 10 to 15-min prior to the $T_c$ inflection point, an upward rise in HR was evident in all tests.
Figure 5.2. Critical environmental limits on a standard psychrometric chart. Values are means ± SE for 7 lean and 7 obese subjects at 34, 36 and 38°C and 7 lean and 5 obese subjects at 42°C. Compared to lean subjects, obese subjects consistently had significantly lower critical water vapor pressure ($P_{crit}$) values in each warm environment. *Significant group difference at $P < 0.03$. 
Chapter 6

CONCLUSIONS

The three studies that comprise this dissertation were designed to: 1) determine the effects of exercise heat-induced 2% DEH and EUH with a 6% CES compared to P EUH on basketball skill performance measures within a simulated game context in highly-skilled young players; 2) determine the degree of natural acclimatization and artificially-induced acclimation-related changes during repeated exercise / heat bouts in 9- to 12-yr-old lean and obese boys during the summer months; and 3) determine the critical environmental limits for exercising heat-acclimated 9- to 12-yr-old lean and obese boys. The purpose of this chapter is to summarize results from these studies and to discuss implications for future research.

Fluid Balance and Basketball Performance

The main findings from the study “2% Dehydration Impairs and 6% Carbohydrate Drink Improves Boys Basketball Skills” (Chapter 3) were that deterioration in basketball skill performance in skilled 12- to 15-yr-old boys accompanied 2% DEH and that EUH with a 6% CES significantly improved shooting skill performance and on-court sprinting in this subject population over EUH with a P. Subjectively, adding 6% carbohydrate (CES EUH) resulted in diminished feelings of fatigue and lightheadedness by the end of the simulated “game” compared to the 2% DEH trial. This degree of improvement is important in a sport where subtle changes in skill performance could be the deciding factor in winning or losing a basketball game.
**Heat-Acclimatization / Acclimation**

The main findings from the study “Responses of Lean and Obese Boys to Repeated Summer Exercise-Heat Bouts” (Chapter 4) were that during the summer months, obese (compared to lean) 9- to 12-yr-old boys are less naturally heat-acclimatized as indicated by significantly higher baseline $T_c$. In addition, obese boys display a significantly slower rate of decrease in exercise $T_c$ and less of an elevation in sweating rate during repeated bouts of light-to-moderate exercise at a similar relative intensity (30% $\dot{V}o_{2\text{max}}$) in a warm, humid environment compared to their lean counterparts. After 6 days of artificial heat-acclimation, baseline $T_c$ in obese children reached that of lean children on day 1, whereas by day 6 lean children acclimated to a new baseline $T_c$. Since obese children started at a higher baseline $T_c$, and acclimate at a slower rate, this suggests that they require additional exercise / heat bouts in order to achieve a degree of acclimation similar to that of lean children.

**Critical Environmental Limits**

The main finding from the study “Critical Environmental Limits for Exercising Heat-Acclimated Lean and Obese Boys” (Chapter 5) was that during light-to-moderate intensity exercise at a similar relative intensity (30% $\dot{V}o_{2\text{max}}$) in a warm environment the critical environment limits for heat-acclimated obese vs. lean 9- to 12-yr-old children are shifted downward on a psychrometric chart, toward a lower $P_{\text{crit}}$. Above these limits, thermal balance cannot be maintained, and a continuous rise in $T_c$ is evident. This suggests that separate guidelines which set restraints on activities at differing levels of climatic heat stress should be tailored to obese and lean children exercising in the heat.
**Implications for Future Research**

Several areas of future research are implied from findings presented in this dissertation. Results from Chapter 3 suggest that DEH impairs and CES ingestion improves basketball skill performance in 12- to 15-yr-old boys. Basketball is a sport characterized by short bouts of high-intensity intermittent activity. Studies in children investigating the impact of DEH and CES ingestion on performance in other sports characterized by short duration, high-intensity intermittent activity (i.e. soccer, football, etc.) are needed. In addition, repeating the study in Chapter 3 with girls would elucidate potential sex-differences. Subjects between studies (girls vs. boys) would need to be matched for age, fitness level, skill level, and body composition.

Results from Chapter 4 suggest that obese vs. lean boys acclimate at a slower rate during repeated exercise / heat bouts during the summer months. Since this was the first study to compare acclimation-related changes during repeated exercise-heat bouts between lean and obese boys, additional studies, conducted in the winter months are needed to either confirm or refute this finding. In addition, repeating the study in Chapter 4 with girls would elucidate potential sex-differences. Subjects between studies (girls vs. boys, both lean and obese) would need to be matched for age, fitness level, maturation stage, and body composition.

Results from Chapter 5 suggest that during light-to-moderate intensity exercise in a warm environment heat-acclimated obese compared to lean 9- to 12-yr-old boys display attenuated critical environmental limits, above which a continuous rise in Tc is observed. Since adipose tissue has a lower specific heat of stored lipid (0.40 kcal•kg\(^{-1}\)•°C\(^{-1}\) adipose tissue vs. 0.82 kcal•kg\(^{-1}\)•°C\(^{-1}\) entire human body) storing the same amount of heat would induce a greater rise in temperature in adipose vs. lean tissue (30). Thus, adipose tissue could be considered as one of the factors which account for these lower limits. Since, during the maturation process, young
girls acquire a greater percentage of body fat compared to boys this suggests that during exercise, young girls may also display attenuated critical environmental limits. Therefore, repeating the study in Chapter 5 with girls would elucidate potential sex-differences. Subjects between studies (girls vs. boys, both lean and obese) would need to be matched for age, fitness level, maturation stage, and body composition.

Finally, there is a lack of empirically-derived, field-based studies addressing issues relating to thermoregulation and fluid balance in exercising children. Answers to basic questions such as “Outside of the laboratory, how hot do athletes / active children get during exercise in hot and/or humid conditions?” or “What are common levels of DEH attained by children during team sport competition or routine play?” are unclear. Providing answers to these and other questions are important because they will impact the exercising child’s physical performance, subjective comfort and/or physical well-being during exercise in the heat. Characterizing the temperature responses of the exercising child in field-based studies will allow investigators to discern if the conditions which are reproduced in the laboratory are representative of that which happen in the field.


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Appendix A

INFORMED CONSENTS / CHILD VERBAL ASSENTS

Informed consent for basketball study:

Title of Project: Effect of Hydration Status on Basketball Performance: 12-15 year old boys – combined
IRB# 19290

Principal Investigator: W. Larry Kenney, Ph.D. W: 814-863-1672
Graduate Students: Kelly Dougherty W: 814-863-2948, H: 814-238-8626
Lindsay Baker W: 814-863-2948, H: 814-238-4349
Research Assistant: Jane Pierzga W: 814-865-1236, H: 814-692-4720

This is to certify that I, ____________________, on behalf of my minor child ____________________, have been given the following information with respect to my child's participation as a volunteer in a program of investigation under the supervision of Dr. W. Larry Kenney.

1. Purpose of the study: Playing sports places demands upon the bodies and minds of athletes. Athletes' abilities to meet these demands affect how well they perform. Food, rest, drink, and other factors can affect an athletes' success. This study explores the effect of dehydration on how well a basketball player performs. Dehydration is when the amount of water in the body is less than normal. This study has 5 trials. Two trials look at the affect of dehydration on playing basketball. These trials cause dehydration by having the player workout in a hot room until the desired amount of his body’s water is lost through sweating. The amount of water-loss is tracked by weighing the body before and during the workout. The other trials look at the effect of a sports drink and a simulated sports drink on how well the player performs. The amount of water in the body stays normal for these trials. All trials use one of 2 sets of basketball drills to create a mock basketball game to test how well the player’s body performs. Drill Set 1 includes frequent rest periods. Drill Set 2 has fewer and shorter rest periods. A blood sample is taken to make sure that the player is able to be in the study. For each trial, the player swallows a special pill that measures the warmth inside the body. This research is sponsored by the National Basketball Association.

2. Procedures to be followed: Your child will participate on the circled days. Please read the descriptions of the circled days and procedures. Then write your initials by the circled days and procedures. Your child has 2 days of screenings and 5 days of trials. The trials are at least about 1 week apart. Your child may be asked to repeat a trial or screening at the discretion of the researcher or medical staff. Your child does not have to repeat a trial or screening if he does not wish to. The researcher may request a repeat if something happens that causes the trial to stop or hurts the quality of the data. The researcher could ask for a repeat because of computer failure, for instance. If your child is not allergic to lidocaine, he may request that the researcher use numbing cream for the insertion of any needles into his skin.
initial Day 1 (Screening 1): On the evening before his first visit to the Noll Lab, your child will not eat or drink after 9 PM. During his first visit, your child will report to the General Clinical Research Center (GCRC). The staff or nurse draws 15 ml (1 Tbsp) of blood from your child’s arm to check his state of wellness. After the blood draw, your child receive a breakfast bar and juice, if he wishes. His blood pressure, height, weight, and resting ECG are measured. The researcher measures the thickness of skin folds at various sites on your child’s body to determine his % body fat.

initial Day 2 (Screening 2): You child will eat a light breakfast before coming to the lab. He will bring shorts, t-shirt, and shoes in which he can run. Your child will have a check-up that includes his health history by the GCRC medical staff. The researcher measures your child’s maximum vertical leap. A graded exercise test (GXT) measures your child’s fitness. You child runs on a treadmill during the test. The treadmill’s steepness gets greater every 2 minutes. The staff measures your child’s blood pressure and heart rate. The researcher straps a heart rate monitor around your child’s chest. He wears a nose clip and breathes into a tube so the researcher can collect the air he breathes out. Your child rates how hard he is working by using a numbered scale (rating of perceived exertion or RPE scale). Although, running becomes harder, the test’s results are best if your child does his best to run as long as he can. However, he may stop at any time. The test is about 12 minutes long.

initial Days 3 – 7 (Trials):
Trials: The trials must occur within 30 days of having your child’s height, weight, and % body fat measured. We will re-record these measures before any trial that does not occur within the 30 days. You will obtain the T-pill at Noll Lab before each trial.

Drill Set 1 Trials:
Dehydration (Water Loss) Trial: Your child will workout in a warm, dry room (35°C or 95°F; 20% relative humidity) to decrease his body’s water by 2%. The researcher checks how much water he loses by weighing him during the workout. For instance, if he weighs 100 lbs., he needs to lose 2 lbs. When your child has lost enough water, he drinks water during the rest of the workout to prevent more weight loss.

Normal Hydration (Normal Water) Trial: Your child will workout in a warm, dry room (35°C or 95°F; 20% relative humidity). He will drink to keep his body weight the same. The researcher checks how much water your child loses by weighing him during the workout and gives him the right amount of drink.

Drill 2 Set Trials:
Dehydration (Water Loss) Trial: Your child will workout in a warm, dry room (35°C or 95°F; 20% relative humidity) to decrease his body’s water by 2%. The researcher checks how much water he loses by weighing him during the workout. For instance, if he weighs 100 lbs., he needs to lose 2 lbs. When your child has lost enough water, he drinks water during the rest of the workout to prevent more weight loss.

Normal Hydration (Normal Water) with Sports Drink or with Simulated Sports Drink Trials: Your child will work out in a warm, dry room (35°C or 95°F; 20% relative humidity). He will drink to keep his body weight the same. The researcher checks how much water your child loses by weighing him during the workout and gives him the right amount of drink. During the drills, your child will consume a sports drink or a simulated sports drink (contains no sugars).

Trial Procedure:
You will help your child to start up the battery of the temperature pill and swallow the pill during the evening before the trial. Then your child will not eat or drink for the rest of the evening before the trial. When he arrives at the lab, the staff measures his heart rate and blood pressure. Then the researcher straps a heart rate monitor around his chest. The trial proceeds as follows. The timeline is a guide.

7:30 – 8:00 AM Your child eats a standard breakfast supplied by the lab.
Measurements: weight, urine sample.

8:00-10:00 AM Your child works out in a warm, dry room (35°C or 95°F; 20% relative humidity).
Workout: Bike, treadmill.
Measurements: weight, heart rate, blood pressure, body temperature, rating of perceived exertion (RPE), urine sample, fatigue survey.
Depending upon the trial, your child may or may not drink during the workout.
10:00-11:00 AM  
Your child rests at normal room temperature. The researcher gives him the right amount of drink to keep the right amount of water in his body.  
Measurement: body temperature, heart rate.

11:00 AM -12:00 PM  
The researcher takes your child to a basketball court. Your child performs basketball drills.  
Measurements: Drill performance rating, RPE, heart rate, body temperature, urine sample, weight, fatigue surveys at halftime and after drill session.  

After the trial, your child will be fed a standard lunch. Your child’s heart rate and blood pressure are measured before he goes home.

Measurements: Your child may have a person of the same sex do the measure, if he wishes.

Skin Fold Measurements: Your child’s percent body fat is measured using a tool that looks like tongs. The tongs gently measure the thickness of skin folds at several places on his body.

Blood draw: During the screening, skilled nurse or staff will take blood from your child’s arm using a needle. The nurse or staff uses safety measures and sterile techniques that are used in hospitals.

ECG: The staff attaches twelve ECG electrodes (sticky patches) to your child’s chest on Day 1 to measure his heart's activity and rate.

Heart Rate (Polar Monitor): The researcher straps a Polar Monitor belt around your child’s chest to measure heart rate.

Blood pressure: A cuff is inflated on your child’s upper arm. The staff slowly releases the air from the cuff and listens to the area at the inside of his elbow with a stethoscope.

Graded Exercise Test (GXT): The test measures your child’s fitness. First, he walks on a treadmill to warm up. Then he runs on the treadmill. Your child can choose the speed at which he walks and runs. The treadmill’s steepness gets greater every 2 minutes. The staff measures your child’s blood pressure and heart rate. A clip holds his nose shut. He breathes into a tube that collects the air he breathes out. Your child rates how hard he is working by pointing to a number on a chart (rating of perceived exertion or RPE scale). Although running becomes harder, the test’s results are best if your child does his best to run as long as he can. He may stop at any time. The test is 10-20 minutes long.

Metabolic Measurements: Your child breathes into a tube that collects the air he breathes out. The researcher also measures the volume, oxygen, and carbon dioxide he breathes out.

Ratings of Perceived Exertion (RPE) Scale: Your child points to a number next to the phrase that best describes how hard he is working.

Fatigue Survey: The survey has sets of words that may describe how your child feels. A line connects the words in each set. He makes a mark on the line closer to the words in a set that best describe how he feels. The closer his mark is to the words, the better the words describe how he feels.

Core Temperature (T-pill): The T-Pill has been used for many years. Researchers have used the pill in astronauts, fire fighters, scuba divers, and people climbing mountains. The system has 2 parts:

1. T-pill – The T-pill is a small sensor that uses a radio signal to report the temperature in your child’s body.  
On the night before each trial, you will help your child to wake the battery in the T-pill by removing and throwing away the T-pill’s wrapper. Then your child swallows the T-pill with water as if it were a vitamin. The T-pill is slippery when wet so he must be careful when swallowing it. The T-pill stays inside of your child’s body for about 2 days. After the trial, your child looks for the T-pill to pass from his body.

2. The recorder – The recorder reads and stores the radio signal from the T-pill. The researcher straps the recorder around your child’s waist.

Body Weight: Your child dries dripping sweat from his skin and stands on a scale to be weighed.

Urine Sample: Your child urinates into a container at certain times during the trial.

Maximum Vertical Leap: Your child stands with arms held fully extended over his head. The researcher measures the distance from the floor to his fingertips. Your child jumps as high as he can. The researcher measures the distance from the floor to his fingertips at the peak of the jump. The researcher subtracts the first measure from the second.

Basketball Drills: Most basketball players know these drills. The researcher makes sure that your child knows how to do the drills. He needs to use his best effort. The drills, described below, mock a basketball game.
Drill Set 1
About 1 1/3 hours total: Four 12 min quarters, 10-min break between quarters, 15-min break between halves

1st Quarter
- **shooting** – X-out lay-ups (start at elbow, dribble in for lay-up, dribble to opposite elbow, dribble in for lay-up, repeat) – record # makes in one minute
- 1.5 min rest
- **speed** - one “suicide” – measure time to completion (suicide = a series of runs: baseline to foul line and back; to mid court and back; to opposite foul line and back; full court and back)
- 1.5 min rest
- **explosiveness** - vertical jumps – hit target on wall (80% max) 10 times – measure time to completion
- 1.5 min rest
- **agility** - defensive slides (zigzags) two lengths of court – measure time to completion
- 1.5 min rest
- **shooting** – around the world – record # makes in one minute
- 1.5 min rest
- **combo** – around perimeter and on midline of court: sprint forward, defensive slides across midline, sprint forward, defensive slides across baseline, backpedal to midline, defensive slides across, backpedal to baseline, defensive slides across
- 10 minutes (rest, drink)

2nd Quarter
- **shooting** – 3 pointers (from 7 spots) – record # makes in one minute
- 1.5 min rest
- **speed** – run width of court 10 times – measure time to completion
- 1.5 min rest
- **explosiveness** - vertical jump – record best of 3 (express as %max)
- 1.5 min rest
- **agility** – 20 lane slides (defensive slides across width of key) – measure time to completion
- 1.5 min rest
- **shooting** – free throws - record # makes out of 10 attempts
- 1.5 min rest
- **combo** – around the key: sprint forward, diagonal defensive slides to baseline, sprint forward, diagonal defensive slides to baseline, repeat – measure time to complete 5
- 15 minute halftime (rest, drink)

3rd Quarter – Repeat 1st Quarter drills
- 10 minutes (rest, drink)

4th Quarter – Repeat 2nd Quarter drills

Drill Set 2:

1st Quarter
- **shooting** – X-out lay-ups (start at elbow, dribble in for lay-up, dribble to opposite elbow, dribble in for lay-up, repeat) – record # makes in one minute
- **speed** - one “suicide” – measure time to completion (suicide = a series of runs: baseline to foul line and back; to mid court and back; to opposite foul line and back; full court and back)
- **explosiveness** - vertical jumps – hit target on wall (80% max) 10 times – measure time to completion
- **agility** - defensive slides (zigzags) two lengths of court – measure time to completion
- **shooting** – around the world – record # makes in one minute
- **combo** – around perimeter and on midline of court: sprint forward, defensive slides across midline, sprint forward, defensive slides across baseline, backpedal to midline, defensive slides across, backpedal to baseline, defensive slides across
- 5 minutes (rest, drink)
2nd Quarter
• shooting – 3 pointers (from 7 spots) – record # makes in one minute
• speed – run width of court 10 times – measure time to completion
• explosiveness – vertical jump – record best of 3 (express as %max)
• agility – 20 lane slides (defensive slides across width of key) – measure time to completion
• shooting – free throws - record # makes out of 10 attempts
• combo – around the key: sprint forward, diagonal defensive slides to baseline, sprint forward, diagonal defensive slides to baseline, repeat – measure time to complete 5
• 10 minute halftime (rest, drink)

3rd Quarter – Repeat 1st Quarter drills
• 5 minutes (rest, drink)

4th Quarter – Repeat 2nd Quarter drills

3. Discomforts and risks:
Skin Fold Measurements: Your child may feel embarrassed having this measure. The researcher makes this measure in a private and professional way.
Blood draw: Blood draws often cause mild pain, bruising, swelling, or bleeding. There is also a slight chance of infection or a small clot. Your child may become lightheaded or may faint. Your child may request numbing cream on his skin to reduce the pain from the needle. To keep the chance of infection small, the staff or nurse uses the same methods used in hospitals.
ECG: The staff tapes ECG wires to your child’s body. There are no risks, but the tape may redden or irritate his skin for a while.
Heart Rate (Polar Monitor): There are no risks to this measurement.
Blood pressure: The researcher uses the method used in a doctor’s office. During the short time the cuff is inflated, your child’s arm may feel tingly or numb. Rarely, the cuff may cause a temporary bruise.
Graded Exercise Test (GXT): Your child will likely have tiredness, sweating, and breathlessness. He will also have increased heart rate and muscle fatigue. He may also have lightheadedness, fainting, nausea, or muscle cramp, but these occur less frequently. More severe reactions include irregular heartbeat, heart attack, and death. Severe reactions are very rare in your child’s age group. It is possible for your child to stumble or fall on the treadmill leading to cuts, scrapes, dislocations, broken bones, head injury, abnormal heart rhythms, or even death. Your child will be taught the safe use of the treadmill and watched closely during the test. All changes in speed will be made slowly, and he will be assisted on and off the treadmill.
Metabolic Measurements: The tube’s holder can feel awkward. Your child may feel disturbed by the slight change in airflow due to the valves in the tube. These changes do not last long.
Ratings of Perceived Exertion (RPE) Scale and Fatigue Survey: Your child should not worry if his answer is “right enough.” The only “right” answer is one that best describes how he feels.
Core Temperature (T-pill): Swallowing the T-pill presents risks like that of taking a vitamin pill such as choking or gagging on the pill or water. The pill becomes slippery when wet so your child must be careful. There have been no reports of abdominal problems with the T-pill. However, the pill could cause cramps, irritation, blockage, or infection. Your child may feel shy about watching for the T-pill to pass. However, seeing the T-Pill pass is the best way to know for sure that it has left his body. If your child has not seen the T-pill pass within 4 days, he reports to the lab. The researcher uses the recorder to check for the T-pill’s presence. The recorder’s failure to find a radio signal at this time likely shows that the T-pill passed without your child’s seeing it. In the unlikely event of severe stomach or intestinal problems after the 4 days, an x-ray may be needed to show for sure that the pill has passed from your child’s body. If the T-pill fails to pass from his body, he may need surgery to remove it. Only once a T-pill been removed by surgery. This happened years ago in another lab. Before swallowing the T-pill, the person had surgery that made a pocket in his gut. The T-Pill became stuck in the pocket. Your child will not be in this study if he has had surgery in his abdomen. Magnetic Resonance Imaging (MRI) is a medical test that can cause the T-pill to overheat and be dangerous. Your child cannot have an MRI within 2 weeks after having swallowed a T-pill unless he has seen the T-Pill pass from his
body. If he needs an MRI and has not seen the T-Pill pass, you will tell his doctor that your child has swallowed a T-Pill.

**Body Weight, Urine Sample:** Your child may feel embarrassed having this measure. The researcher makes this measure in a private and professional way.

**Maximum Vertical Leap and Basketball Drills:** The drills make your child sweat and increase his heart rate and blood pressure. The drills make your child feel fatigued and breathless. This is part of playing basketball and running drills. Your child may stop at any time. Working his body can produce strains, sprains, and soft tissue tears. Head/neck injury and broken bones are possible. Since the drills mock a basketball game, he is not exposed to many of the parts of the game that can result in such injuries. Therefore, the risk of these injuries is less than that from a real game. The screening will further reduce the unlikely risk of serious heart or breathing problems.

**Dehydration:** Dehydration means having less water than normal in the body. Researchers track your child’s body’s water-loss by measuring the change his body’s weight. The amount of water-loss in this study is common in children working in the heat. People have studied water-loss in children. In one study, children lost 1-2% of their body weight when they worked in the heat. In another study, researchers watched children in a sporting event. Over 1/3 of the children lost over 1.5% of their body-weight. Some lost more than 3% of their body-weight. The water-loss in this study can make your child feel thirsty. He may have a headache or a mild stomach cramp.

**Exercise in the heat:** Your child will feel hot and may get thirsty. Tiredness, sweating, breathlessness, increased heart rate, and muscle fatigue are normal. There is a small chance that the workouts may cause nausea, dizziness, or muscle cramps. The remote chance of irregular heartbeats, heart attack, or death is less than that for the GXT. You child will tell the researcher about any problems and may stop at any time.

**Numbing Cream:** Your child will not use the numbing cream if he is sensitive to lidocaine. Anbesol and Orajel are common drugs similar to the numbing cream. When your child uses the cream, all feelings within the treated area are blocked. Therefore, he must avoid scratching, rubbing, or exposing the treated sites to very hot or cold temperatures at until complete sensation has returned. During or right after the cream is applied, mild swelling, skin redness or strange feelings may develop at the site of treatment. In studies on intact skin of cream-treated subjects, one or more such local reactions were noted in 56% of patients. The reactions were mild and short-lived. The reactions stopped without help in 1 or 2 hours. No serious reactions resulted from the use of the cream. Allergic reactions, although rare, can occur. Whole body adverse reactions from correct use of the cream are unlikely due to the small dose absorbed. If effects do occur, they are like those seen with other local numbing agents. These may include feeling faint, nervous, dizzy, or sleepy. Your child could also have twitching, and vomiting. Reactions may be brief or not all.

4. **a. Benefits to your child:** You and your child receive information about his health and fitness. He will be given an assessment of his basketball performance. He also learns about the importance of hydration in the performance of basketball.

   **b. Potential benefits to society:** The results of this study can benefit coaches, players, and others who care about young basketball athletes. We will learn how reduced water in the body affects the young athlete. Also, this study may suggest that the sports drink can fight these affects. This study could cause people to think about the impact of decreased water in the body on young athletes in other sports.

5. **Alternative procedures which could be utilized:**
The researcher could measure the warmth of your child’s body in other ways. Some of these techniques are not accurate enough for this project. Some of the techniques cannot be used when someone works out or drinks. Some of these techniques are like the T-pill in many ways, but are more unpleasant. The other techniques in the study are used in research worldwide. They are the best means by which to meet the goals of this study with minimal discomfort and risk to your child.

6. **Time duration of the procedures and study:** This study requires 7 main visits. Day 1 (screening and orientation 1) will take about 4 hours. Day 2 (screening and orientation 2) will take about 4 hours. Sessions 3-7
(trials) will last about 7 hours each. You will pick up the T-pill at Noll Lab before each trial. The trials are at least about 1 week apart. Additional visits for re-orientations before trials may be necessary.

7. **Statement of confidentiality:** The data is available only to the investigators and authorized personnel of Penn State University’s Office of Research Protections and Institutional Review Board. Volunteers are coded by an identification number for statistical analyses. All records are kept in a secure place. All records associated with your child’s participation in the study will be subject to the usual confidentiality standards applicable to medical records (e.g., such as records maintained by physicians, hospitals, etc.), and in the event of any publication resulting from the research no personally identifiable information will be disclosed.

8. **Right to ask questions:** If you have any questions or concerns about the research or your child’s participation in the present investigation, please contact Lindsay Baker (W: 814-863-2948, H: 814-238-4349), Kelly Dougherty (W: 814-863-2948, H: 814-238-8626), or Jane Pierzga (W: 814-865-1236, H: 814-692-4720). If there are findings during the research that could relate to your child’s wanting to help with the study, you will be told of the findings. You may contact the Office for Research Protections, 212 Kern Graduate Building, University Park, PA 16802, (814) 865-1775 for additional information concerning your child’s rights as a research participant.

I have been given an opportunity to ask any questions I may have, and all such questions or inquiries have been answered to my satisfaction.

9. **Compensation:** Your child is paid $150.00 for each of the 5 trials. For each trial, he is paid an amount of money equal to the part of the trial that he completes. For instance, if he completes only half of the trial, he is paid $75.00 for that trial. This is because $75.00 is one half of $150.00. The total amount that he is paid is $750.00. He gets a T-shirt. Your child may be asked to repeat a trial. If he agrees to repeat a trial, he will be paid an additional $75.00 for each trial that he repeats.

Total payments within one calendar year that exceed $600 will require the University to annually report these payments to the IRS. This may require your child to claim the compensation that he receives for participation in this study as taxable income.

10. **Injury Clause:** Medical care is available in the event of injury resulting from research but neither financial compensation nor free medical treatment is provided. Your child is not waiving any rights that he may have against the University for injury resulting from negligence of the University or the investigators. Questions regarding this statement or your child’s rights as a subject of this research should be directed to the Office for Research Protections in 212 Kern Building, University Park, PA (814-865-1775).

11. **Voluntary participation:** Your child’s participation in this study is voluntary, and he may withdraw from this study at any time by telling the investigator. Your child’s withdrawal from this study or refusal to participate will in no way affect your child’s care or access to medical services. Your child may decline to answer specific questions. However, his acceptance into the study may be contingent upon answering these questions. Your child’s helping with the study may be ended without your consent if the researcher deems that your child’s health or behavior adversely affects the study or increases risks to your child beyond those approved by the Office for Research Protections and agreed upon by you in this document.

12. In the event that abnormal test results are obtained, you will be told of the results immediately and told to contact your private medical provider for follow-up.

This is to certify that I consent to and give permission for my child’s participation as a volunteer in this program of investigation. I understand that I will receive a signed copy of this consent form. I have read this form, and understand the content of this consent form.
Child ASSENT:
I want to be a part of this study, and I may also read the consent form. I can stop at any time, and nothing will happen to me. I may refuse to answer any question. When the researchers are finished with this study, they will write a report about what was learned. This report will not include my name or that I was in the study. I can ask any questions about the study at any time or call Lindsay Baker (W: 814-863-2948, H: 814-238-4349), Kelly Dougherty (W: 814-863-2948, H: 814-238-8626), or Jane Pierzga (W: 814-865-1236, H: 814-692-4720).

I, the undersigned, have witnessed and do attest to the fact that the study has been defined and explained to the minor child and that the minor child has indicated his assent of his own free will.

Dr. Kenney is a member of Gatorade’s Sports Medicine Review Board.
Child verbal assent for basketball study:

Verbal Assent Form for Clinical Research Study
The Pennsylvania State University

Title of Project:  Effect of Hydration Status on Basketball Performance: 12-15 year old boys - combined
IRB# 19290
Sponsor: National Basketball Association

Principal Investigator:  W. Larry Kenney, Ph.D.  W: 814-863-1672

You should be in the study only if you want to be in the study. We try hard not to talk anyone into doing anything that they do not wish to do. If you do not want to do the study, please let us know. If you decide to be part the study but change your mind later, you may stop anytime you wish.

This study explores the effect of dehydration on how well you can play basketball. Dehydration is when the amount of water in the body is less than normal. For some trials, you will be dehydrated. For the other trials, you will consume a sports drink or a fake sports drink.

We screen you to make sure that you can be in our study safely. We also need to know that you fit within the guidelines for our study. During the 2 screening days, we measure your height, weight, blood pressure, heart rate, %body fat, and heart activity. The trials must occur within 30 days of having your height, weight, and %body fat measured. We will re-record these measures before any trial that does not occur within the 30 days. None of these tests hurt. We measure your heart rate by feeling your pulse at your wrist. To measure blood pressure, we place a cuff around your upper arm. We inflate the cuff so that it squeezes your arm. We listen to the area at the inside of your elbow while we slowly deflate the cuff. Your arm may feel a little numb and tingly while the cuff is tight, but this lasts only about a minute. To measure your heart’s activity, we put sticky disks on your chest. We connect the disks to a machine while you lie quietly for several minutes. To measure your %body fat, we measure the thickness of folds of skin at several places on your body using special tongs. We will talk to you about your health history. We also measure the highest distance you can jump. Probably the blood draw and exercise test will seem the scariest to you. The blood draw is on the first day. You do not eat or drink during the night before the blood draw. We draw blood through a needle placed in a vein in your arm for about a minute. The needle usually hurts a little, but the pain is brief. You may request numbing cream on your skin to reduce the pain from the needle. The exercise test is on the second day. During this test, you run on a treadmill. You breathe into a tube that collects air you breathe out. Every 2 minutes the treadmill gets steeper so the run gets harder. You point to numbers on a chart telling us how tired you feel. The test lasts about 10 minutes. For the best results, you need to work hard during the test; however, you may stop at any time. The test may make you hot, sweaty, breathless, and tired.

You have 5 days of trials. You may be asked to repeat a trial. You do not have to if you do not want to. On each day, you will have a workout in a very warm room and then do basketball drills. On the night before each trial, you swallow a pill that measures the warmth inside your body. Be careful swallowing the pill. The pill is slippery when it’s wet. On the morning of the trial, you eat breakfast in the lab. We measure body warmth, heart rate, blood pressure, weight, and tiredness during the trials. A device that straps to your waist records your body warmth from the pill inside you. We collect urine samples during the trial by having you urinate in a cup. We measure tiredness with surveys that asks you questions. Two trials look at dehydration’s effect on how well you play basketball. For these trials, you work out on a treadmill and bike in a very warm room until you sweat enough water from your body. The amount of sweat you lose is tracked by weighing your body before and during the workout. You will probably get hot and thirsty. The other trials look at the effect of a sports drink or a fake sports drink on how well you play basketball. Like in the other trials, you work out in a very warm room, but you replace any sweat you lose by drinking the sports drink or the fake sports drink. You will probably get hot during this workout, too. After the workouts, you go to the gym to do running, agility, and shooting drills.
We have two sets of drills. We split each set of drills into quarters with short rest periods. One set has fewer and shorter rest periods than the other set. You will do only one set of drills in each trial. We record how well you do the drills. You drink during the rest periods so that your weight does not change any more. You work hard during the drills. You need to do your best, but you may stop at any time. You will probably get hot, tired, sweaty, and breathless like when you play basketball. It is possible for you to have injuries like falls or sprains like you can when you play basketball. You eat lunch at the lab.

It is unlikely that the pill will get stuck inside you. Just in case, for 4 days after the trial, you watch for the pill to pass when you go to the bathroom. This can be yucky, but it is the easiest way to know for sure that the pill has passed. If you do not see the pill, you need to come to the lab. We use the recorder to see if the pill is still there.
Informed consents for heat acclimation and critical environmental limits studies:

Informed Consent Form for Clinical Research Study
The Pennsylvania State University

Title of Project: Safe Ambient Conditions For Exercising Kids

Principal Investigator: Kelly Dougherty  W: 814-863-2948, H: 814-238-8626
Faculty Advisor: W. Larry Kenney, Ph.D. W: 814-863-1672
Research Assistant: Jane Pierzga W: 814-865-1236, H: 814-692-4720

This is to certify that I, ___________________, on behalf of my minor child ___________________, have been given the following information with respect to my child's participation as a volunteer in a program of investigation under the supervision of Dr. W. Larry Kenney.

1. **Purpose of the study:** Exercise helps a child to stay healthy and fit. Parents and people who work with children must ensure the health and safety of a child while he/she is active. The conditions in the room in which a child works out can affect the success and safety of a child during exercise. This study has up to 12 trials. The first series of visits up to 8 total trials look at how the body changes to make exercise in a warm room feel easier. We compare these changes in lean and heavier children. The next 4 trials look at the levels of warmth and humidity in the room and how they affect a child’s body temperature during exercise. The study compares these levels between lean and heavier children. For each trial, your child swallows a special pill (Tpill) that measures the warmth inside the body. During trials, he works out on a treadmill and/or bike in a warm room. The findings of the study will provide guidelines for safe exercise conditions for lean and heavier children.

2. **Procedures to be followed:** Your child will participate on the circled days. Please read the descriptions of the circled days and procedures. Then write your initials by the circled days and procedures. Your child may end any procedure at any time. Please note that no measurements / procedures are optional. All measurements and procedures must be completed in order to be in the study.

If your child has screened within 6 months, he does not have to screen again. Your child has 2 screening visits and up to 12 days of trials. The trials will be no more than 4 days apart. Your child may be asked to repeat a trial or screening at the discretion of the researcher or medical staff. Your child does not have to repeat a trial or screening if he does not wish to. The researcher may request a repeat if something happens that causes the trial to stop or hurts the quality of the data. The researcher could ask for a repeat because of computer failure, for instance.

______ initial Day 1 (Screening 1): On the evening before his first visit to the Noll Lab, your child does not eat or drink after 9 PM. During his first visit, your child reports to the General Clinical Research Center (GCRC). The staff or nurse draws 15 ml (1 Tbsp) of blood from your child’s arm to check the cells, fats, and normal substances in his blood. After the blood draw, your child receives a breakfast bar and juice, if he wishes. The staff measures his blood pressure, height, weight, and resting...
ECG. Your child will answer questions on a survey called the Physical Self Description Questionnaire which will help to determine how active he is on a daily / weekly basis.

**Initial Day 2 (Screening 2):** Your child eats a light meal before coming to the lab. Your child brings shorts, t-shirt, socks, and shoes in which he can exercise. Your child has a check-up that includes his health history by the GCRC medical staff. As part of the check-up, the GCRC staff notes your child’s state of puberty. This test uses the Tanner method that visually compares your child’s genitals and pubic hair to standard photos. The pubertal evaluation will be conducted in a private room by a female GCRC medical staff member. Your child has a whole body dual energy X-ray absorptiometry (DXA) scan to measure the amount of fat and lean mass in his body. For this test, your child dresses in shorts and T-shirt. He removes all metal objects (pocket change, watches, earrings, necklaces, etc.). He will lay still on a table for about 10 minutes. The table slowly glides beneath the DXA as the machine scans his body. Next your child has a graded exercise test (GXT) that measures your child’s fitness. This test allows the researcher to decide your child’s workout-level for the trials. Your child walks at a slow to fast pace on a treadmill during the test. The treadmill’s speed and steepness get greater every 3 minutes. The staff measures your child’s blood pressure and heart rate. During the test, 12 lead ECG monitoring will be performed. The researcher tapes ECG wires to the skin of your child’s chest. Your child wears a nose clip and breathes into a tube so the researcher can collect the air he breathes out. Your child rates how hard he is working by using a numbered scale (rating of perceived exertion or RPE scale). Although the exercise becomes harder, the test’s results are best if your child does his best to exercise as long as he can. However, he may stop at any time. The test is about 12 minutes long.

**Initial Days 3 – up to 14 (Trials):**

**Trials:** Your child must have his height, weight, and % body fat measured within 30 days of a trial. If these measures are more than 30 days old, we make these measures again. In this case, we will use skin fold thickness to compute %body fat (see “Measurements”). Your child may end any trial at any time.

**Acclimation Trials (Days 3 – up to 10):** There are up to 8 of these trials. These trials get your child’s body used to working out in a warm room. On the day of each trial, your child eats a light meal at least 2 hours before reporting to the lab. Your child does not consume caffeine (i.e. chocolate, coffee, tea, etc.) on the day of the trial. Your child brings comfortable walking shoes, socks, and shorts to the lab.

You must pick up a Tpill from the researcher at Noll Lab on the day before the trial. You help your child to start up the battery of the Tpill and swallow the pill during the evening before the trial. When your child arrives at the lab he will don shorts. The researcher straps a band around the child’s chest to measure heart rate. The researcher weighs your child who is wearing only shorts and collects a urine sample. Your child enters the test chamber that is at 38°C (100.4°F) and 50% relative humidity. The researcher records a baseline blood pressure and heart rate. The researcher also records the warmth of your child’s body. Then your child walks for 20 minutes on a treadmill and then rests for 5 minutes in a chair. Then he rides a bike for 20 minutes and rests for 5 minutes. Lastly, he walks on a treadmill for 20 minutes. Heart rate and body core temperature will be continually monitored during exercise and the rest periods. Blood pressure and RPE will be measured at 10 minute intervals into each exercise bout. Also at this time your child will rate how “hot” he feels by using a numbered scale called the Thermal Sensation scale. During the rests, the researcher checks how much water your child loses through sweating by weighing him. Your child drinks a volume of water that is equal to the weight that he lost.

Your child will repeat the exercise in the heat exposures, up to 8 total visits, until we observed a plateau in either the heart rate or body core temperature response. When this plateau is reach, then that means that your child is heat acclimated and can move onto the next part of the study. Thus, for example, if your child reaches this plateau in 4 visits, then after the 4th visit, your child will move onto
the next part of the study. At the end of the trial, your child will answer questions on a survey called the Physical Activity Enjoyment Scale which will assess how your child feels about the exercise he is performing.

**Pcrit Trials (Days 11-14):** The next 4 trials look at the levels of warmth and humidity in the room and how they affect a child’s body temperature during exercise. The warmth of the room for the trials will be 34°C (93°F), 36°C (97°F), 38°C (100°F) or 42°C (107°F). Your child performs one trial at each level of warmth. Each trial occurs on a separate day. The trials are no more than 4 days apart. The order of the trials is random.

You must pick up a Tpill from the researcher at Noll Lab on the day before the trial. You help your child to start up the battery of the Tpill and swallow the pill during the evening before the trial. On the day of each trial, your child eats a light meal at least 2 hours before coming to the lab. Your child does not consume caffeine (i.e. chocolate, coffee, tea, etc.) on the day of the trial. Your child brings comfortable walking shoes, socks, and shorts to the lab. When your child arrives at the lab he will don shorts. The researcher straps a band around the child’s chest to measure heart rate. The researcher weighs your child who is wearing only shorts and collects a urine sample. Your child enters the test chamber that is at the level of warmth assigned to that day’s trial. The researcher tapes wires to the skin of your child’s right upper arm, lower back, belly, and right thigh. The wires are taped to the skin with adhesive tape. The wires measure the warmth of your child’s skin during the trial. The researcher records a baseline blood pressure and heart rate. The researcher also records the warmth of your child’s body and skin. Each trial begins with a 30-minute baseline during which the warmth and humidity levels are unchanged. Then the amount of water vapor in the air increases a little every five minutes. During this time, the warmth of the room remains unchanged. Throughout the trial, your child walks on a treadmill at about 1/3 of his greatest effort. The researcher measures heart rate, and body and skin warmth throughout the trial. Blood pressure, RPE and thermal sensation are measured every 10 minutes. After 30 minutes, the researcher has your child breathe into a tube for a couple of minutes. The amount of oxygen in the air your child breathes out will show how much your child is working. The experiment ends when your child has completed the protocol or if his body’s warmth exceeds 39°C (102°F). The trial will end if your child shows any adverse signs (sick to stomach, dizzy, etc.). Also, your child can stop the trial at any time. Your child leaves the test chamber. The researcher measures your child’s body weight and collects a urine sample. Also, your child will answer question on a survey called the Physical Activity Enjoyment Scale which will assess how your child feels about the exercise he is performing. The next trial occurs within 4 days.

**Measurements:**

**DXA Scan:** For this test, your child dresses in shorts and T-shirt. He removes all metal objects (pocket change, watches, earrings, necklaces, etc.). He will lay still on a table for about 10 minutes. The table slowly glides beneath the DXA as the machine scans his body.

**Skin Fold Measurements:** Your child’s percent body fat is measured using a tool that looks like tongs. The tongs gently measure the thickness of skin folds at several places on his body.

**Blood draw:** During the screening, a skilled nurse or staff member will take blood from your child’s arm using a needle. The nurse or staff member uses safety measures and sterile techniques that are used in hospitals.

**ECG:** The staff attaches twelve ECG electrodes (sticky patches) to your child’s chest on Day 1 to measure his heart's activity and rate. The ECG will also be used during the graded exercise test.

**Heart Rate (Polar Monitor):** The researcher straps a Polar Monitor belt around your child’s chest to measure heart rate.

**Blood pressure:** A cuff is inflated on your child’s upper arm. The staff slowly releases the air from the cuff and listens to the area at the inside of his elbow with a stethoscope.
**Graded Exercise Test (GXT):**  The test measures your child’s fitness. The researcher uses the test to compute your child’s effort during the trials. First, your child walks on a treadmill to warm up. Then the treadmill’s speed and steepness gets greater every 3 minutes. The staff measures your child’s blood pressure and heart rate. ECG monitoring will be performed. A clip holds his nose shut. He breathes into a tube that collects the air he breathes out. Your child rates how hard he is working by pointing to a number on a chart (rating of perceived exertion or RPE scale). Although the exercise becomes harder, the test’s results are best if your child does his best to exercise as long as he can. He may stop at any time. The test is 10-20 minutes long.

**Metabolic Measurements:** Your child breathes into a tube that collects the air he breathes out. The researcher measures the volume, oxygen, and carbon dioxide he breathes out.

**Ratings of Perceived Exertion (RPE) Scale:** Your child points to a number next to the phrase that best describes how hard he is working.

**Physical Self Description Questionnaire:** Your child answers questions pertaining to how active he is on a daily / weekly basis by circling a number on a piece of paper which corresponds to different phrases ranging from “False”, “Mostly False”, “More False Than True” to “More True Than False”, “Mostly True” and “True”

**Physical Activity Enjoyment Scale:** Your child answers questions pertaining to how he feels about the exercise he is performing by circling a number on a piece of paper which corresponds to different phrases ranging from “Disagree a lot”, Disagree a little”, “Neither agree or disagree” to “Agree a little” and “Agree a lot”.

**Thermal Sensation Scale:** Your child points to a number next to a phrase that best describes how hot he feels.

**Core Temperature (T-pill):** The T-Pill has been used for many years. Researchers have used the pill in children, astronauts, fire fighters, scuba divers, and people climbing mountains. The system has 2 parts:
1. T-pill – The T-pill is a small sensor that uses a radio signal to report the temperature in your child’s body. The T-pill’s wrapper contains a small magnet that keeps the T-pill’s battery turned off. On the night before each trial, you will help your child to turn on the battery in the T-pill by removing and throwing away the T-pill’s wrapper and magnet. Then your child swallows the T-pill with water like he would a vitamin pill. The T-pill is slippery when wet so he must be careful when swallowing it. The T-pill stays inside of your child’s body for about 2 days. After the trial, your child looks for the T-pill to pass from his body.
2. The recorder – The recorder reads and stores the radio signal from the T-pill. The researcher straps the recorder around your child’s waist.

**Body Weight:** Your child dries dripping sweat from his skin and stands on a scale to be weighed. He will be wearing only shorts for this measure during the trials.

**Urine Sample:** Your child urinates into a container at certain times during the trial.

3. **Discomforts and risks:**

**DXA Scan:** The DXA scan exposes your child to a small amount of radiation where the x-ray beam crosses your child’s body. The radiation is the same as a whole body dose of about 1.5 mrem. A mrem is a unit of whole body radiation dose. For comparison, 1.5 mrem is less than your child would receive from a routine chest x-ray. Also, 1.5 mrem is less than that from the cosmic rays your child would receive during a coast-to-coast flight. Five days of local, normal background radiation is more than 1.5 mrem.

**Skin Fold Measurements:** Your child may feel embarrassed having this measure. The researcher makes this measure in a private and professional way.
Blood Draw: Blood draws often cause mild pain, bruising, swelling, or bleeding. There is also a slight chance of infection or a small clot. Your child may become lightheaded or may faint. To keep the chance of infection small, the staff or nurse uses the same methods used in hospitals.

ECG: The staff tapes ECG wires to your child’s body. There are no risks, but the tape may redden or irritate his skin for a while.

Heart Rate (Polar Monitor): There are no risks to this measurement.

Blood Pressure: The researcher uses the method used in a doctor’s office. During the short time the cuff is inflated, your child’s arm may feel tingly or numb. Rarely, the cuff may cause a temporary bruise.

Graded Exercise Test (GXT): Your child will likely have tiredness, sweating, and breathlessness. He will also have increased heart rate and muscle fatigue. He may also have lightheadedness, fainting, nausea, or muscle cramp, but these occur less frequently. More severe reactions include irregular heartbeat, heart attack, and death. Severe reactions are very rare in your child’s age group. It is possible for your child to stumble or fall on the treadmill leading to cuts, scrapes, dislocations, broken bones, head injury, abnormal heart rhythms, or even death. Your child will be taught the safe use of the treadmill and watched closely during the test. All changes in speed will be made slowly, and he will be assisted on and off the treadmill.

Metabolic Measurements: The mouth piece, tube connected to the mouth piece and the head gear can feel awkward. Your child may feel disturbed by the slight change in airflow due to the valves in the tube. These changes do not last long.

Ratings of Perceived Exertion (RPE) Scale: Your child should not worry if his answer is “right enough.” The only “right” answer is one that best describes how he feels.

Physical Self Description Questionnaire: Your child should not worry if his answer is “right enough”. The only “right” answer is one that best describes how active he is on a daily / weekly basis.

Physical Activity Enjoyment Scale: Your child should not worry if his answer is “right enough”. The only right answer is the one that best describes how he feels about the exercise he is performing.

Thermal Sensation Scale: Your child should not worry if his answer is “right enough”. The only “right” answer is the one that best describes how hot he feels.

Core Temperature (T-pill): Swallowing the T-pill presents risks like that of taking a vitamin pill such as choking or gagging on the pill or gagging on the water. The pill becomes slippery when wet so your child must be careful. Your child may feel shy about watching for the T-pill to pass. However, seeing the T-Pill pass is the best way to know for sure that it has left his body. If your child has not seen the T-pill pass within 4 days, he reports to the lab. The researcher uses the recorder to check for the T-pill’s presence. The recorder’s failure to find a radio signal at this time likely shows that the T-pill passed without your child’s seeing it. There have been no reports of abdominal problems with the T-pill. However, the pill could cause cramps, irritation, blockage, or infection. In the unlikely event of severe stomach or intestinal problems after swallowing the T-pill, an x-ray may be needed to see if the pill has passed from your child’s body. If the T-pill fails to pass from his body, he may need surgery to remove it. Only once has a T-pill been removed by surgery. This happened years ago in another lab. Before swallowing the T-pill, the person had surgery that made a pocket in his gut. The T-Pill became stuck in the pocket. Your child will not be in this study if he has had surgery in his abdomen. Magnetic Resonance Imaging (MRI) is a medical test that can cause the T-pill to overheat and be dangerous. Your child cannot have an MRI while the T-pill is in the body. If he needs an MRI and you think the T-pill might still be in your child’s body, you must tell his doctor that your child has swallowed a T-Pill. Your doctor may call us for more information.

Body Weight, Urine Sample: Your child may feel embarrassed having this measure. The researcher makes this measure in a private and professional way.

Exercise in the Heat: Your child will feel hot and may get thirsty. Tiredness, sweating, breathlessness, increased heart rate, and muscle fatigue are normal. There is a small chance that the
workouts may cause nausea, dizziness, or muscle cramps. The remote chance of irregular heartbeats, heart attack, or death is less than that for the GXT. You child will tell the researcher about any problems and may stop at any time.

**Pubertal Evaluation:** Your child may feel embarrassed having this measure. The pubertal evaluation will be conducted in a private room by a female GCRC medical staff member.

4. **a. Benefits to your child:** You and your child receive information about his health and fitness.

   **b. Potential benefits to society:** The results of this study will provide information from which guidelines can be written. These guidelines will help to ensure the health and safety of a child while he/she is exercising in a hot and/or humid environment.

5. **Alternative procedures which could be utilized:** The researcher could measure the warmth of your child’s body in other ways. Some of these techniques are not accurate enough for this project. Some of the techniques cannot be used when someone works out or drinks. Some of these techniques are like the T-pill in many ways, but are more unpleasant. The DXA used in this study has a good mix of accuracy and ease. There are other tools for measuring your child’s body fat. Some of those methods are not as accurate or easy for your child as the DXA. The other techniques in the study are used in research worldwide. They are the best means by which to meet the goals of this study with minimal discomfort and risk to your child.

6. **Time duration of the procedures and study:** This part of the study requires up to 14 main visits. If your child has screened within 6 months, he does not have to screen again. Day 1 (screening) will take about 30 minutes. Day 2 (screening) will take about 2 hours. Test days 1- up to 8 (trials) will last about 2 hours each day. Test days 9-12 (trials) will last about 3 hours each day. For this study there are up to 14 days and up to 30.5 hours total. You will pick up the T-pill at Noll Lab before each trial. There will be up to 12 days of T-pill ingestions.

7. **Statement of confidentiality:** The data is available only to the investigators. Volunteers are coded by an identification number for statistical analyses. All records are kept in a secure location. All records associated with your participation in the study will be subject to the usual confidentiality standards applicable to medical records (e.g., such as records maintained by physicians, hospitals, etc.), and in the event of any publication resulting from the research no personally identifiable information will be disclosed. The Office of Human Research Protections in the U.S. Department of Health and Human Services, the U.S. Food and Drug Administration (FDA), the Office for Research Protections at Penn State and the Biomedical Institutional Review Board may review records related to this project.

8. **Right to ask questions:** If you have any questions or concerns about the research or your child’s participation in the present investigation, you may contact Kelly Dougherty (W: 814-863-2948, H: 814-238-8626), or Jane Pierzga (W: 814-865-1236, H: 814-692-4720). You may also contact them if you feel that your child has been harmed by this study. If there are findings during the research that could relate to your wanting your child to help with the study, you will be told of the findings. You
can also call this number if you have complaints or concerns about the research. If you have questions about your child’s rights as a research participant, or you have concerns or general questions about the research, contact The Pennsylvania State University’s Office for Research Protections at (814) 865-1775.

I have been given an opportunity to ask any questions I may have, and all such questions or inquiries have been answered to my satisfaction.

9. Compensation: Up to $300 total broken down into:

Heat acclimation: Your child could receive up to a total of $160 for these 8 trials. Your child receives $20 for each trial he completes. Your child receives a T-shirt for completing the first 4 trials. He receives a cinch bag when he completes the last 4 trials.

Determination of Pcrit: Your child could receive a total of $120 for these 4 trials. Your child receives $30 for each trial he completes.

Bonus for completion of study: $20

If your child completes only part of a trial, your child receives payment that is equal to the amount of the trial he completes. For example, your child receives $10 for completing 1/2 of a Heat Acclimation trial. Your child could be asked to repeat a trial. For example, this could occur if there were a problem with the computer during the first trial. If your child decides to repeat a trial, he receives payment for that extra trial. Your child may choose not to repeat the trial.

Total payments within one calendar year that exceed $600 will require the University to annually report these payments to the IRS. This may require your child to claim the compensation that he receives for participation in this study as taxable income.

10. Injury Clause: In the unlikely event your child becomes injured as a result of his participation in this study, medical care is available. It is the policy of this institution to provide neither financial compensation nor free medical treatment for research-related injury. By signing this document, you are not waiving any rights that your child has against The Pennsylvania State University for injury resulting from negligence of the University or its investigators.

11. Voluntary participation: Your child’s being in this study is voluntary. You may withdraw your child from this study at any time by telling the researcher. If you decide to withdraw your child, you will not have a penalty or loss of benefits you would receive otherwise. You or your child may decline to answer certain questions. You or your child may decide not to comply with certain procedures. However, your child’s being in the study may be contingent upon answering these questions or complying with the procedures. The researcher may end your child’s role in the study without your consent if the researcher deems that your child’s health or behavior adversely affects the study or increases risks to your child beyond those approved by the Institutional Review Board and agreed upon by you and your child in this document. You and your child have been given an opportunity to ask any questions you may have, and all such questions or inquiries have been answered to your and your child’s satisfaction.

12. In the event that abnormal test results are obtained, you will be told of the results immediately and told to contact a private medical provider for follow-up.
13. The approximate number of subjects to be involved in this study is 8 per group or 16 total.
14. In the event of a research injury, the following people can be contacted:

Principal Investigator: Kelly Dougherty W: 814-863-2948, H: 814-238-8626
Faculty Advisor: W. Larry Kenney, Ph.D. W: 814-863-1672
Research Assistant: Jane Pierzga W: 814-865-1236, H: 814-692-4720

This is to certify that I consent to and give permission for my child's participation as a volunteer in this program of investigation. I understand that I will receive a signed and dated copy of this consent form. I have read this form, and understand the content of this consent form.

Parent/Legal Guardian ___________________________ Date ___________

Child ASSENT:

I want to be a part of this study, and I may also read the consent form. I can stop at any time, and nothing will happen to me. I may refuse to answer any question. When the researchers are finished with this study, they will write a report about what was learned. This report will not include my name or that I was in the study. I can ask any questions about the study at any time or call Kelly Dougherty (W: 814-863-2948, H: 814-238-8626), or Jane Pierzga (W: 814-865-1236, H: 814-692-4720).

Child Name (Parent Print) ___________________________ Child Assent Signature ___________________________ Date ___________

I, the undersigned, have witnessed and do attest to the fact that the study has been defined and explained to the minor child and that the minor child has indicated his assent of his own free will.

Witness ___________________________ Date ___________

I, the undersigned, have defined and explained the studies involved to the above volunteer.

Person obtaining consent ___________________________ Date ___________
Child verbal assent for heat acclimation and critical environmental limits studies:

Verbal Assent Form for Clinical Research Study
The Pennsylvania State University

Title of Project: Safe Ambient Conditions For Exercising Kids

Sponsor: National Institutes of Health

Principal Investigator: Kelly Dougherty W: 814-863-2948, H: 814-238-8626
Faculty Advisor: W. Larry Kenney, Ph.D. W: 814-863-1672

You should be in the study only if you want to be in the study. We try hard not to talk anyone into doing anything that they do not wish to do. If you do not want to do the study, please let us know. If you decide to be part of the study but change your mind later, you may stop anytime you wish. Please note that no measurements / procedures are optional. All measurements and procedures must be completed in order to be in the study.

Purpose: Sessions 1- up to 8 explore the effect of the warmth of a room and the amount of water in the air on how well you can work out. Also, these sessions get your body used to walking in a warm room which might take up to 8 sessions. But, if your body gets used to walking in a warm room more quickly, then you might have fewer sessions. Sessions 9-12 find out the amount of warmth and water in the air that make the warmth of your body start to rise quickly.

Screenings: We screen you to make sure that you can be in our study safely. We also need to know that you fit within the guidelines for our study. During the 2 screening days, we measure your height, weight, blood pressure, heart rate, %body fat, heart activity and how active you are. None of these tests hurt. We measure your heart rate by feeling your pulse at your wrist. To measure blood pressure, we place a cuff around your upper arm. We inflate the cuff so that it squeezes your arm. We listen to the area at the inside of your elbow while we slowly deflate the cuff. Your arm may feel a little numb and tingly while the cuff is tight, but this lasts only about a minute. To measure your heart’s activity, we put sticky disks on your chest. We connect the disks to a machine while you lie quietly for several minutes. To measure your %body fat, you dress in shorts and T-shirt. You must remove all metal objects (pocket change, watches, earrings, necklaces, etc.). You lay still on a table for about 10 minutes. The table slowly glides beneath the special machine that scans your body without touching it. We may also measure your %body fat a different way later. At that time, we measure the thickness of folds of skin at several places on your body using special tongs. We ask you questions on a piece of paper about how active you are and you circle the answer that best describes you. We will talk to you about your health history. Probably the blood draw and exercise test will seem the scariest to you. The blood draw is on the first day. You do not eat or drink during the night before the blood draw. We draw blood through a needle placed in a vein in your arm for about a minute. The needle usually hurts a little, but the pain is brief. The exercise test is on the second day. During this test, you walk on a treadmill. You breathe into a tube that collects air you breathe out. Every 3 minutes the treadmill gets faster and steeper so the walk gets harder. You point to numbers on a chart telling us how tired you feel. The test lasts about 12 minutes. For the best results, you need to work hard during the test; however, you may stop at any time. The test may make you hot, sweaty, breathless, and tired. Lastly,
the GCRC staff will note your puberty stage. A female GCRC medical staff member will visually compare your genitals and pubic hair to standard photos. The pubertal evaluation will be conducted in a private room.

**Experiments**: You have up to 12 sessions. You may be asked to repeat a session. You do not have to if you do wish. In each session, you work out in a very warm room. On the night before the sessions, you swallow a pill that measures the warmth inside your body. Be careful swallowing the pill. The pill is slippery when it’s wet. On the morning of the session, you eat a light meal at least 2 hours before coming to the lab. We measure body warmth, heart rate, blood pressure, weight, and tiredness during the sessions. At times, you breathe into a tube that collects air you breathe out. In some sessions, we tape wires to your skin to measure its warmth. A device strapped to your waist records your body’s warmth from the pill inside you. We collect urine samples in sessions by having you urinate in a cup. We measure tiredness with a survey that asks you questions. In another survey, you will point to a number next to a phrase that best describes how “hot” you feel. For sessions 1- up to 8, you walk on a treadmill for 20 minutes; then rest for 5 minutes. Then you bike for 20 minutes; then rest for 5 minutes. Lastly, you walk for 20 minutes. We track the amount of sweat you lose by weighing your body. You drink water to replace the weight you lose. We ask you how you felt about the exercise with a survey that asks you questions on a piece of paper and you circle the answer that best describes you. For sessions 9-12, you walk on a treadmill in a very warm room. Some days will be warmer than others. While you walk, the amount of water in the air will rise. We stop these sessions when we see the warmth of your body start to rise more quickly. You need to do your best, but you may stop at any time. You will probably feel hot and sweaty. You may get tired during the sessions. You may get thirsty during the last 4 sessions. We measure how hot you feel with a survey, where you will point to a number next to a phrase that best describes how “hot” you feel. We ask you how you felt about the exercise with a survey that asks you questions on a piece of paper and you circle the answer that best describes you.

**Temperature Pill**: It is unlikely that the pill will get stuck inside you. Just in case, for 4 days after the session, you watch for the pill to pass when you go to the bathroom. This can be yucky, but it is the easiest way to know for sure that the pill has passed. If you do not see the pill, you need to come to the lab. We use the recorder to see if the pill is still there.
Addendum consent for critical environmental limits study:

Title of Project: Safe Ambient Conditions For Exercising Kids

Principal Investigator: Kelly Dougherty  W: 814-863-2948, H: 814-238-8626
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Research Assistant: Jane Pierzga  W: 814-865-1236, H: 814-692-4720

This is to certify that I, ____________________, on behalf of my minor child ____________________, have been given the following information with respect to my child's participation as a volunteer in a program of investigation under the supervision of Dr. W. Larry Kenney.

1. **Purpose of the addendum consent:** This addendum consent is to inform you of a change in the determination of the critical water vapor pressure (Pcrit) trials (Days 11-14). The warmth of the room for one of the Pcrit trials will be 42°C (107°F) instead of 28°C (82°F). This change does not increase the risk to your child. Although the starting temperature is higher, the relative humidity at which body core temperature is forced upward will be lower. All of the same safety precautions will still be in place i.e. if your child’s body warmth reaches 39°C, if your child experiences adverse signs (nausea, dizziness, etc) or if your child desires to stop, the experiment will end. All of the other information in the original informed consent remains unchanged.

This is to certify that I consent to and give permission for my child’s participation as a volunteer in this modified protocol of investigation. I understand that I will receive a signed and dated copy of this addendum consent form. I have read this form, and understand the content of this addendum consent form.

Parent/Legal Guardian  Date

**Child ASSENT:**
I want to be a part of this study, and I may also read the addendum consent form. I can stop at any time, and nothing will happen to me.

Child Name (Parent Print)  Child Assent Signature  Date

I, the undersigned, have witnessed and do attest to the fact that the study change has been defined and explained to the minor child and that the minor child has indicated his assent of his own free will.

Witness  Date
I, the undersigned, have defined and explained the studies involved to the above volunteer.

<table>
<thead>
<tr>
<th>Person obtaining consent</th>
<th>Date</th>
</tr>
</thead>
</table>
Appendix B

SUPPLEMENTAL DATA

Data from the Physical Activity Enjoyment Scale and urine variables were not presented in their entirety in both Chapter 4 and 5. Therefore, they are presented below. Table B.1 and B.2 are from the “Responses of Lean and Obese Boys to Repeated Summer Exercise-Heat Bouts” study (Chapter 4) and Table B.3 and B.4 are from the “Critical Environmental Limits for Exercising Heat-Acclimated Lean and Obese Boys” study (Chapter 5).
Table B.1. Subjective responses to the physical activity enjoyment scale by day of heat acclimation

<table>
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<tr>
<th>Question</th>
<th>Day 1</th>
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<th>Day 3</th>
<th>Day 4</th>
<th>Day 5</th>
<th>Day 6</th>
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</table>

Values are means ± SE for 7 lean and 7 obese subjects.
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<th>Day 1</th>
<th>Lean</th>
<th>Obese</th>
<th>Lean</th>
<th>Obese</th>
<th>Lean</th>
<th>Obese</th>
<th>Lean</th>
<th>Obese</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre</td>
<td>75 ± 33</td>
<td>45 ± 14</td>
<td>4 ± 0.2</td>
<td>4 ± 0.5</td>
<td>1.023 ± 0.01</td>
<td>1.020 ± 0.01</td>
<td>963 ± 20</td>
<td>801 ± 79</td>
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<tr>
<td>Post</td>
<td>52 ± 7</td>
<td>44 ± 6</td>
<td>5 ± 0.5</td>
<td>4 ± 0.6</td>
<td>1.025 ± 0.01</td>
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<td>Obese</td>
<td>Lean</td>
<td>Obese</td>
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<td>Obese</td>
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<td>Pre</td>
<td>76 ± 28</td>
<td>54 ± 16</td>
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<td>4 ± 0.4</td>
<td>1.022 ± 0.01</td>
<td>1.026 ± 0.01</td>
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<td>906 ± 34</td>
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<td>64 ± 16</td>
<td>33 ± 7</td>
<td>4 ± 0.4</td>
<td>5 ± 0.4</td>
<td>1.023 ± 0.01</td>
<td>1.028 ± 0.01</td>
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<td>Lean</td>
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<td>55 ± 6</td>
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<td>Lean</td>
<td>Obese</td>
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<td>Obese</td>
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<td>Lean</td>
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<td>Obese</td>
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</table>

Values are means ± SE for 7 lean and 7 obese subjects. $U_{vol}$, urine volume; $U_{col}$, urine color; $U_{sg}$, urine specific gravity; $U_{osmol}$, urine osmolality.
Table B.3. Subjective responses to the physical activity enjoyment scale by trial

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<th>Question</th>
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<th>36°C Obese</th>
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<th>42°C Obese</th>
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Values are means ± SE for 7 lean and 7 obese subjects at 34, 36 and 38°C and 7 lean and 5 obese subjects at 42°C.
**Table B.4. Urine variables for the critical environmental limits study**

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<th>Temp (°C)</th>
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<th>Uvol (mL)</th>
<th>Ucol</th>
<th>Usg (UG)</th>
<th>Uosmol (mosmol)</th>
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<td>Lean</td>
<td>Obese</td>
<td>Lean</td>
<td>Obese</td>
<td>Lean</td>
</tr>
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<td>34°C</td>
<td>Pre</td>
<td>68 ± 19</td>
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<td>4 ± 0.6</td>
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<tr>
<td></td>
<td>Post</td>
<td>70 ± 19</td>
<td>77 ± 17</td>
<td>4 ± 0.3</td>
<td>5 ± 0.6</td>
</tr>
<tr>
<td>36°C</td>
<td>Pre</td>
<td>73 ± 34</td>
<td>80 ± 21</td>
<td>4 ± 0.5</td>
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<td>71 ± 14</td>
<td>4 ± 0.5</td>
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<td>38°C</td>
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<td>69 ± 17</td>
<td>3 ± 0.4</td>
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<td>76 ± 18</td>
<td>50 ± 12</td>
<td>4 ± 0.6</td>
<td>4 ± 0.7</td>
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<tr>
<td>42°C</td>
<td>Pre</td>
<td>43 ± 17</td>
<td>66 ± 37</td>
<td>4 ± 0.3</td>
<td>5 ± 0.5</td>
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<td>52 ± 6</td>
<td>40 ± 4</td>
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<td>5 ± 0.5</td>
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</tbody>
</table>

Values are means ± SE for 7 lean and 7 obese subjects at 34, 36 and 38°C and 7 lean and 5 obese subjects at 42°C. Uvol, urine volume; Ucol, urine color; Usg, urine specific gravity; Uosmol, urine osmolality.
Vita

Kelly A. Dougherty

EDUCATION

2004-2008        Ph.D. in Kinesiology; emphasis in Exercise Physiology
                 The Pennsylvania State University, University Park, PA
2002-2004        M.S. in Kinesiology; emphasis in Exercise Physiology
                 The Pennsylvania State University, University Park, PA
1993-1998        B.S in Physical Education; emphasis in Corporate Fitness
                 The College of New Jersey (formerly Trenton State College), Ewing, NJ

PEER REVIEWED PUBLICATIONS

1. Baker LB, Dougherty KA, Chow M, Kenney WL. Progressive dehydration causes a
   2007.

2. Leidy HJ, Dougherty KA, Frye BR, Duke KM, Williams NI. 24 hr ghrelin is elevated after

3. Dougherty KA, Baker LB, Chow M, Kenney WL. Two percent dehydration impairs and six
   percent carbohydrate drink improves boys basketball skills. *Med Sci Sports Exerc.* 38(9): 1650-

RESEARCH SUPPORT

2007-2008        American College of Sports Medicine Foundation Award
                 Carl V. Gisolfi Memorial Student Research Grant
                 “SAFE KIDS: Safe Ambient conditions For Exercising KIDS”
                 Amount: $5,000
                 Role: PI

2007            Graduate Student Research Endowment
                 College of Health and Human Development, The Pennsylvania State University
                 “SAFE KIDS: Safe Ambient conditions For Exercising KIDS”
                 Amount: $500
                 Role: PI

INVITED ORAL SCIENTIFIC PRESENTATIONS

“2% dehydration impairs and 6% carbohydrate drink improves boy’s basketball performance”
2006 Annual Meeting of the American College of Sports Medicine, Denver, CO, June 2, 2006

“Effects of dehydration and euhydration on basketball skills in 12-15 year old boys”
Noll Physiological Research Seminar Series, The Pennsylvania State University, April 7, 2006