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Do Metabolic and Psychosocial Responses To Exercise Explain Ethnic/Racial Disparities in Insulin Resistance?

Rebecca Elizabeth Hasson

University of Massachusetts Amherst, rhasson@kin.umass.edu

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**DO METABOLIC AND PSYCHOSOCIAL RESPONSES TO EXERCISE
EXPLAIN ETHNIC/RACIAL DISPARITIES IN INSULIN RESISTANCE?**

A Dissertation Presented

by

REBECCA E. HASSON

Submitted to Graduate School of the
University of Massachusetts Amherst in partial fulfillment
of the requirements for the degree of

DOCTOR OF PHILOSOPHY

February 2009

Department of Kinesiology

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Approved as to style and content by:

Barry Braun, Co-Chair

Patty S. Freedson, Co-Chair

David X. Marquez, Member

John Staudenmayer, Member

Gary Bennett, Non-voting Member

Graham Caldwell, Graduate Program Director
Department of Kinesiology

ABSTRACT

DO METABOLIC AND PSYCHOSOCIAL RESPONSES TO EXERCISE EXPLAIN ETHNIC/RACIAL DISPARITIES IN INSULIN RESISTANCE?

FEBRUARY 2009

REBECCA E. HASSON, B.S., UNIVERSITY OF MASSACHUSETTS, AMHERST

M.S., UNIVERSITY OF MASSACHUSETTS, AMHERST

Ph.D., UNIVERSITY OF MASSACHUSETTS, AMHERST

Directed by Professors Barry Braun and Patty S. Freedson

INTRODUCTION: Non-Hispanic blacks (blacks) are more insulin resistant compared to non-Hispanic whites (whites), increasing their risk for Type 2 diabetes. The role played by ethnic/racial disparities in the response to physical activity in mediating those higher rates of insulin resistance in blacks is unknown. Because the beneficial effects of exercise are transient and require subsequent doses of exercise to maintain the effect; the metabolic and psychosocial responses to single exercise bouts have strong implications for both opposing insulin resistance and raising the probability that an individual will continue to exercise. **PURPOSE:** To compare the metabolic and psychosocial responses to individual bouts of exercise, at the intensity and duration corresponding to the current Institute of Medicine guidelines, in blacks and age/gender/BMI-matched whites. **METHODS:** Insulin sensitivity (hyperinsulinemic-euglycemic clamp) and metabolic flexibility (suppression of resting fat oxidation) along with exercise task self-efficacy, mood, and state-anxiety were assessed before and after a bout of exercise in black and white men and women (metabolic $n = 21$; psychosocial $n = 31$). Participants walked on a treadmill at 75% of maximum heart rate for 75 minutes. Exercise sessions were repeated on three separate occasions to assess the cumulative change in psychosocial responses to exercise. **RESULTS:** There were no ethnic/racial differences in baseline measures of whole-body insulin sensitivity ($p = 0.95$). Black participants demonstrated larger improvements in the insulin sensitivity response to individual bouts of exercise compared to their white counterparts (+18% vs. -1.8%), which was primarily the result of enhanced non-oxidative glucose disposal during the clamp. Additionally, blacks demonstrated a greater capacity to switch from primarily fat oxidation at rest to primarily carbohydrate oxidation during the clamp ($p < 0.003$). There were no ethnic/racial differences in the psychosocial response to individual bouts of exercise; individual bouts of exercise improved exercise task self-efficacy and reduced psychological distress in both black and white participants ($p = 0.006$). Black participants reported higher positive in-task mood during all three bouts of exercise ($p = 0.003$) and lower RPE scores ($p = 0.04$) during the third exercise bout compared to white participants, despite similar heart rates in both groups. **CONCLUSIONS:** These data demonstrate that metabolic and psychosocial responses to individual bouts of exercise do not help to explain the increased insulin resistance and lower adherence rates to exercise programs reported in blacks compared to

whites. If these results are confirmed in a larger, more diverse, free-living population, future research should focus on social determinants of insulin resistance and physical inactivity to obtain a better understanding of the root causes of increased risk of Type 2 diabetes in black populations.

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CHAPTER I

INTRODUCTION

The prevalence of Type 2 diabetes is increasing at epidemic rates and the risk for non-Hispanic blacks (blacks) is two-fold higher than for non-Hispanic whites (whites) (12, 20, 47). This ethnic/racial disparity is associated with more severe insulin resistance, even when adjusted for obesity (e.g. body fat and fat distribution) (38, 39, 41, 72). On the other hand, exercise reduces the risk of diabetes by decreasing insulin resistance (16, 18, 28, 43-45). A portion of the improvement in insulin action is due to true adaptations to chronic training (11, 59) but the majority of the effect is transient and wanes within 2-3 days following exercise (45, 58). Consequently, each exercise bout can be conceptualized as a pharmacological dose; when taken in sufficient quantity it induces desired metabolic effects for a limited period of time, requiring subsequent doses to maintain the effect.

Relative to insulin sensitive individuals, men and women who are insulin resistant exhibit lower fat oxidation in the fasted state and do not effectively switch to primarily carbohydrate oxidation in the insulin-stimulated state. This condition has been termed “metabolic inflexibility” (53-56). During exercise, insulin resistant women use less muscle glycogen and oxidize more lipid compared to insulin sensitive women matched for adiposity (15). Compared to whites, blacks appear to be less metabolically flexible; i.e. fat oxidation is lower at rest (22) and there is a blunted shift towards carbohydrate oxidation during epinephrine infusions (8). Therefore, if blacks are more insulin resistant than whites on average, they may respond differently to exercise. In support of this hypothesis, Hasson *et al* (43) reported that one bout of moderate intensity exercise

improved insulin sensitivity in black women with insulin-resistance but the effect was smaller than what previous researchers had observed in white cohorts (28, 45). No study to date has directly compared the effects of individual bouts of exercise on insulin sensitivity between blacks and whites.

Understanding the metabolic response to individual bouts of exercise does not address the fact that so few individuals exercise on a regular basis. Thus, it is important to understand the effect of each exercise bout on psychosocial outcomes that influence whether or not the individual will continue to take the “exercise drug”. Despite the numerous cardiometabolic benefits associated with regular exercise, physical activity rates in blacks are significantly lower compared to their white counterparts (21). The ethnic/racial disparity in physical activity does not appear to be the result of apathy towards exercising in blacks, but to more attrition from exercise programs (93). More blacks reportedly start exercise programs compared to whites (17) but adherence to exercise programs is significantly lower in blacks (93). Although the data are derived from only one study, “feeling better” was the number one reason blacks reported engaging in regular physical activity (17). In general, individual bouts of exercise are associated with improved mood (relatively lasting emotional or affective state) (5, 17, 25, 26); decreased state-anxiety (a self-evident but transient emotional state characterized by feelings of apprehension and heightened autonomic nervous system activity) (60); and improved exercise self-efficacy (confidence to complete an exercise task) (57). It is important to understand the effect of each exercise bout on psychosocial outcomes because it is likely that the improvement in mood, state-anxiety and self-efficacy has an influence on whether or not an individual will adopt or adhere to an exercise program. A

less positive response to each exercise bout may explain why blacks are more likely to discontinue exercise programs. No study to date has directly examined potential ethnic/racial differences in psychosocial outcomes of individual bouts of exercise in blacks and whites.

Statement of Problem

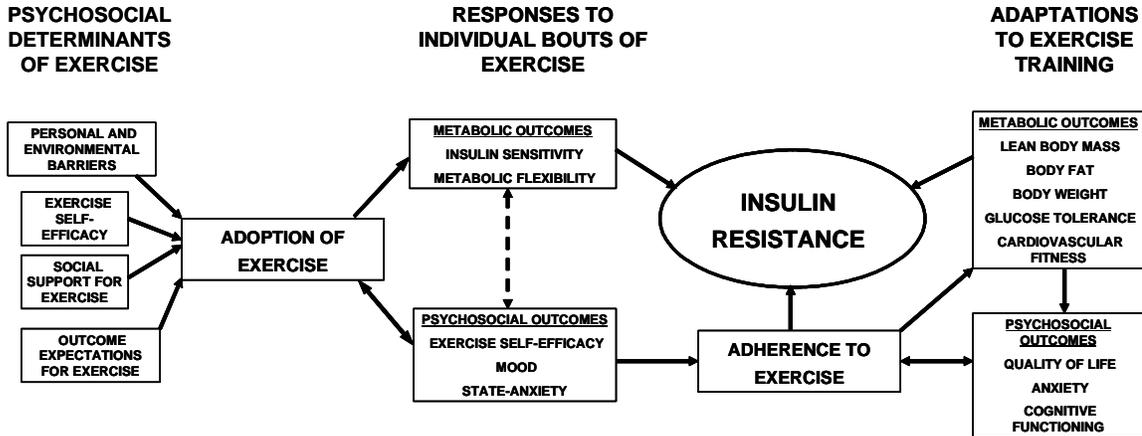
The metabolic and psychosocial determinants and outcomes of exercise can be illustrated using a theoretical framework (see Figure 1). The adoption of exercise is influenced by psychosocial determinants (6) of exercise presented on the left side of Figure 1. The amount of exercise that one chooses to participate in is, in part, explained by personal and environmental determinants for exercise (self-regulatory exercise self-efficacy, social support for exercise, outcome expectations for exercise, and perceived barriers) (6).

Starting an exercise program can elicit immediate metabolic and psychosocial improvements in health (see middle of Figure 1). Metabolic responses to a single bout of exercise include improved insulin sensitivity (16) that lasts for approximately 24-72 hours (57). As previously stated, individual bouts of exercise play the largest role in attenuating insulin resistance (28, 43). *No study to date has directly compared post-exercise insulin sensitivity in blacks and whites.* Additionally, individual bouts of exercise can improve psychosocial outcomes including mood (5, 25, 26), state-anxiety (60), and exercise task self-efficacy (57). These outcome variables can directly influence an individual's likelihood of adhering to an exercise program. *No study to date has directly compared psychosocial responses to individual bouts of exercise in blacks and whites.*

Adherence to an exercise program can elicit metabolic and psychosocial adaptations (19, 88) (see right side of Figure 1); improvements in body composition, glucose tolerance and cardiovascular fitness reduce insulin resistance (74). Psychosocial adaptations to exercise training can include improvements in quality of life (88), anxiety (60, 84) and cognitive function (68). These adaptations can enhance adherence to an exercise program and further reduce insulin resistance.

Ethnic/racial differences in any of these variables could potentially explain the increased prevalence of insulin resistance in blacks. Ethnic/racial differences in the response to individual bouts of exercise have been insufficiently addressed, despite its potential role in mediating insulin resistance in blacks.

Figure 1: Metabolic and Psychosocial Determinants and Outcomes to Acute and Chronic Exercise: A Theoretical Model.



In summary, the metabolic and psychosocial responses to single exercise bouts have strong implications for both decreasing insulin resistance (28, 43) and increasing the probability that an individual will continue to exercise (6). Clarifying the complicated relationships between ethnicity/race, physical activity, and insulin resistance requires the

investigation of both metabolic and psychosocial factors that connect them. Therefore, the specific aims of this dissertation project were:

Aims

Aim 1: To compare the metabolic and psychosocial responses to individual bouts of exercise in blacks and age/gender/BMI-matched whites, and

Aim 2 (Exploratory): To assess the cumulative improvements in. Psychosocial responses to exercise were assessed before and after three bouts of exercise. Because each individual bout of exercise will likely influence the response to the next bout of exercise (especially self-efficacy, as a form of past experience), results from the second and third bouts of exercise represent cumulative changes in psychosocial outcomes to individual bouts of exercise.

Hypotheses

Metabolic hypotheses: The effect of exercise to enhance insulin sensitivity during a hyperinsulinemic-euglycemic clamp will be smaller in blacks compared to whites. In addition, the exercise will have a smaller effect to enhance fasting fat oxidation and insulin-stimulated carbohydrate oxidation in blacks compared to whites.

Psychosocial hypotheses: The positive psychosocial effects of single exercise bouts on exercise task self-efficacy, state anxiety, and mood will be smaller in blacks compared to whites.

Significance

Cardiometabolic diseases, for example Type 2 diabetes, disproportionately affect the health of ethnic/racial minority populations in the United States. Lifestyle modifications including exercise are the most effective means to reduce the incidence of

diabetes. Current exercise recommendations are not tailored to specifically target high-risk populations like non-Hispanic blacks. If there are different metabolic and/or psychosocial responses to exercise in blacks compared to whites, it may be appropriate to consider specific exercise recommendations tailored to the elevated risk for diabetes in this population. Similar to the development of race specific pharmacological agents for heart failure, practitioners/clinicians may need to craft exercise prescriptions specifically designed to reduce insulin resistance in blacks. As previously stated, each exercise bout can be conceptualized as a pharmacological dose; when taken in sufficient quantity it induces desired metabolic effects for a limited period of time, requiring a subsequent dose to maintain the effect. Because black individuals are more insulin resistant compared to whites, maximizing the benefits accrued by each exercise dose could effectively reduce their elevated risk for Type 2 diabetes.

Limitations

Overall: By necessity, the study design is constrained by the timeframe and limited resources to be more exploratory than definitive. Since so little is currently known regarding the metabolic and psychosocial responses to individual bouts of exercise in ethnic/racial minorities, information gained from this study will be extremely useful to generate the most urgent hypotheses to be addressed in larger-scale clinical trials.

Individual bouts of exercise vs. habitual training: It is recognized that a single bout of exercise does not reflect the adaptations seen with chronic (weeks/months) exercise training. A body of research has documented that the majority of the improvements to insulin sensitivity are transient effects of recent exercise and are lost 24-72 hours post-exercise. As described earlier, the concept of exercise as a drug (i.e. each

individual dose is important) supports a focus on how to optimize both the metabolic effects (e.g. enhanced insulin sensitivity and metabolic flexibility) and the psychosocial effects (e.g. improved mood, state-anxiety, exercise task self-efficacy) garnered after each exercise bout. Enhancing the improvements associated with individual bouts of exercise can maximize the efficacy of each exercise dose and the probability that a subsequent exercise dose will be taken.

Generalizability: The use of black and white college students from the University of Massachusetts will increase the internal validity by minimizing inter-individual variability but will reduce the external validity because the study environment cannot be generalized to other environments. However, it is important to minimize environmental determinants of insulin resistance and physical inactivity in order to fully examine inherent ethnic/racial differences in the metabolic and psychosocial response to exercise.

Impact of diet: By design, the contribution of habitual diet (i.e., dietary energy balance, macronutrient composition, or other nutritional factors) to ethnic/racial disparities in insulin resistance and risk for Type 2 diabetes are not being addressed in this study. Nevertheless, previous research does not support the hypothesis that blacks are consuming more food compared to their white counterparts (49). To minimize the confounding impact of those factors on the outcomes of interest in the current study, all food will be provided for participants using standardized meals in the 12 hours prior to each blood measurement. Overall, the emphasis will be placed on maintaining habitual levels of physical activity and dietary intake during this study.

Control of exercise conditions: In general, few investigators have maintained strict control over the environmental and other contextual factors that could conceivably

impact the psychosocial responses to exercise. Some of the most obvious factors such as: room temperature and humidity, visual and auditory stimuli, time of day and day of the week will be controlled for in this study. Nevertheless, it is recognized that there are likely myriad other factors that contribute to the psychosocial response to exercise.

Definitions

Race- a human population considered distinct based on physical characteristics. It is important to note that race is predominantly a social and historical construct.

Ethnicity- social groups with a shared history, sense of identity, geography and cultural roots which may occur despite racial differences.

Minority Group- a readily identifiable subset of the U.S. population, which is distinguished by racial, ethnic, and/or cultural heritage (2).

Non-Hispanic Black- persons having origins in any of the black racial groups of Africa (2). For the purposes of this study, the term non-Hispanic black will be used and defined as persons who self-identify themselves as belonging to this ethnic/racial group and have resided in the United States for the past 5 years.

Non-Hispanic white- a person having origins in any of the original peoples of Europe, North Africa, or the Middle East (2). For the purposes of this study, the term non-Hispanic white will be used and defined as persons who self-identify themselves as belonging to this ethnic/racial group and have resided in the United States for the past 5 years.

Physical Activity- any bodily movement produced by skeletal muscles that result in an expenditure of energy above baseline (74).

Exercise- physical activity that is planned or structured; It involves repetitive bodily movement done to improve or maintain one or more of the components of physical fitness which include: cardiorespiratory endurance (aerobic fitness), muscular strength, muscular endurance, flexibility, and body composition (74).

Insulin Action- a measurement of glucose clearance from the blood under conditions of moderate to high plasma insulin concentrations.

Insulin Resistance- a condition characterized by subnormal insulin action and strongly associated with Type 2 diabetes.

Insulin Sensitivity- measurement of insulin action, using a technique that isolates glucose uptake by peripheral (e.g. skeletal muscle) tissue.

Chronic Adaptations- the physiologic outcomes of exercise training which include improvements in cardiovascular fitness, body weight, and fat free mass.

Acute Adaptations- the metabolic outcomes of single bouts of exercise, which do not include improvements in cardiovascular fitness, body weight, and fat free mass.

CHAPTER II

REVIEW OF LITERATURE

Non-Hispanic blacks (blacks) are more insulin resistant compared to non-Hispanic whites (whites), increasing their risk for Type 2 diabetes. The roles played by ethnic/racial disparities in the response to physical activity in mediating those increased rate of increased insulin resistance in blacks are unknown. Because the beneficial effects of exercise are transient and require subsequent doses of exercise to maintain the effect, the metabolic and psychosocial responses to single exercise bouts have strong implications for both opposing insulin resistance and raising the probability that an individual will continue to exercise. Therefore the primary aim of this study was to compare the metabolic and psychosocial responses to individual bouts of exercise in blacks and age/gender/BMI-matched whites.

Insulin resistance is the first stage in the progression towards Type 2 diabetes and is defined as tissue insensitivity to the metabolic effects of insulin. The ethnic/racial disparity in diabetes prevalence has been associated with more severe insulin resistance in blacks. Insulin resistance is rapidly modifiable by changes in physical activity and diet. Both individual bouts of exercise bouts and chronic training reduce insulin resistance (28, 31, 45). To date no study has directly examined ethnic/racial differences in the response to exercise between blacks and whites.

Understanding the metabolic response to physical activity does not address the fact that so few individuals adopt a physically active lifestyle. Despite the numerous metabolic and psychological benefits associated with regular leisure time physical activity, inactivity rates for blacks are significantly higher compared to their white

counterparts (21). Social cognitive variables be important predictors of physical activity among the general population including blacks. Blacks are reported to have higher adoption rates of physical activity but adherence rates are significantly lower compared to whites. It is currently unknown whether psychosocial outcomes of exercise explain the ethnic/racial disparities in physical activity adherence.

Thus, the present review has several objectives. First, this chapter will review those studies that have focused on ethnic/racial differences in the prevalence and pathophysiology of insulin resistance in black populations in the United States. Second, the metabolic responses to exercise will be described. Third, the relationship between physical activity and psychosocial determinants in blacks will be assessed. Finally, the psychosocial responses to individual bouts of exercise will be examined. This information will be employed to develop a research plan designed to assess the impact of metabolic and psychosocial factors on insulin resistance and physical activity adherence in blacks. An understanding of the roles played by metabolic and psychosocial responses to exercise will provide the information needed to address the root causes of the increased rates of insulin resistance in blacks.

Ethnic/racial Disparities in Insulin Resistance

It is consistently reported that blacks are more insulin resistant compared to whites, which significantly increases their risk for Type 2 diabetes (4, 24, 30, 38, 40, 41, 48, 52, 61, 71-73, 85). Increased overall adiposity and physical inactivity rates in blacks are likely to play a role. However, the increased risk reported in blacks is only partially explained by greater overall adiposity or physical inactivity. The Insulin Resistance Atherosclerosis Study (IRAS), a large-scale multi-center epidemiological study, provided

compelling evidence in support of a metabolic predisposition towards insulin resistance in blacks (9). Black participants demonstrated significantly higher fasting and two-hour post-prandial insulin concentrations, higher acute insulin responses (AIR), and lower levels of insulin sensitivity compared to their white counterparts. After statistically adjusting for age, obesity, body fat distribution, self-reported physical activity and percent calories from fat and fiber, the ethnic/racial disparity was still apparent with higher fasting/two-hour post-prandial insulin concentrations, AIR, and lower insulin sensitivity scores in blacks compared to whites. Goran *et al* (9, 38) and Osei *et al* (72) replicated these findings in smaller cohorts of black children and adults, respectively.

Palaniappan *et al* assessed ethnic differences in the association between BMI and fasting insulin concentrations using data from the Third National Health and Nutrition Examination Survey (NHANES III) (73). In black participants, fasting insulin concentrations were higher at lean weights ($BMI \leq 30$) when compared with white participants. Palaniappan concluded that at lower levels of obesity black women have a higher risk of developing diabetes compared to white women. Differences in mean fasting insulin concentration between black and white men at each BMI category were similar to those of women, however this trend was not significant. Ethnic/racial differences in the prevalence of insulin resistance in blacks reported by Goran, Haffner, Osei, and Palaniappan *et al* suggest a metabolic mechanism predisposing blacks towards Type 2 diabetes (38, 41, 72, 73). Although most of the previous research points towards an inherent difference in insulin resistance in blacks, few researchers have matched their participants for metabolic risk factors for Type 2 diabetes.

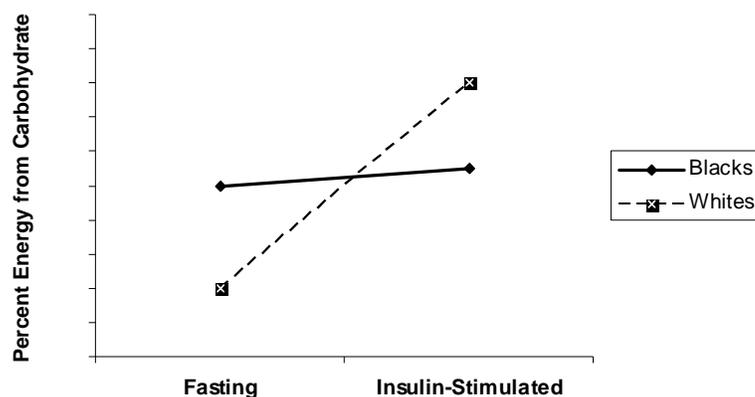
Whether or not a biological predisposition for insulin resistance exists in blacks, the pathophysiology of this condition is different in blacks compared to whites. Decreased hepatic insulin extraction and clearance are the proposed mechanisms for the increased insulin resistance reported in black children and adults (38, 72). Both beta cell secretion and/or insulin clearance by the liver determine peripheral insulin levels. C-peptide is co-secreted in equal proportion with insulin however it is not extracted or metabolized by the liver. Thus, the molar relationship of C-peptide and insulin has been used as a non-invasive method to assess hepatic insulin extraction and insulin clearance in humans (38, 72). Osei *et al* reported significantly lower extraction rates in healthy black participants compared to white subjects. Mean basal hepatic insulin extraction was 33% lower in the black participants compared to whites. Following the ingestion of oral glucose, hepatic insulin extraction decreased by 37% compared to 25% in black and whites, respectively (38, 72). Goran *et al* reported similar findings of decreased hepatic insulin extraction in black versus white children (38).

The etiology of lower hepatic extraction of insulin in black populations is currently unknown. It is hypothesized that decreased hepatic insulin extraction results in hyperinsulinemia, which could lead to peripheral insulin resistance due to the downregulation of peripheral insulin receptors (72). This insulin resistance leads to an increase in pancreatic insulin secretion and further increases in hyperinsulinemia. Although it is commonly believed that insulin resistance leads to hyperinsulinemia, it is possible that increased insulin exposure causes insulin resistance in black populations.

Insulin resistance is associated with a decreased capacity to transition between lipid and carbohydrate fuels (56). Termed “metabolic inflexibility”, this condition was

identified by Kelley and colleagues in obese and Type 2 diabetic individuals (53-56). Metabolic inflexibility is characterized by excessive carbohydrate oxidation in skeletal muscle during fasting conditions and an impaired ability to upregulate carbohydrate oxidation in response to a hyperinsulinemic-euglycemic clamp. Substrate use characteristic of metabolic inflexibility has been reported in blacks compared to whites under varied conditions (8, 22, 69, 91). Weyer *et al* (91) reported black males had higher 24-hour respiratory quotients (lower fat oxidation) compared to white males. Chitwood *et al* and Nicklas *et al* (69) confirmed similar findings in black women compared to white counterparts. Berk *et al* (8) examined substrate oxidation in age/BMI-matched premenopausal black and white women. The white participants increased postabsorptive fat oxidation when switched from a low-fat to high-fat eucaloric diet but this pattern was not observed in black women. Overall, blacks appear to be less metabolically flexible in substrate use compared to whites, which is illustrated in the figure below.

Figure 2. Ethnic/racial Differences in Substrate Utilization during Fasted and Insulin-Stimulated Conditions (Theoretical Data)



Visceral adipose tissue has also been shown to influence insulin sensitivity via increased portal release of free fatty acids and/or abnormal expression and secretion of fat-derived peptides, such as resistin, leptin, and tumor necrosis factor-alpha (79).

Although blacks are generally more obese compared to whites, insulin resistance is weakly associated with visceral adiposity in this ethnic group (3, 50). Blacks tend to have smaller amounts of visceral adipose tissue, but significantly higher rates of insulin resistance compared to their white counterparts. Additionally, blacks have healthier lipid profiles, (lower triglycerides, higher HDL concentrations and higher LDL size) (3, 30, 50, 79) theoretically reducing their risk for Type 2 diabetes. These ethnic/racial differences in fat distribution and lipid profile warrant further investigation as to the underlying mechanism predisposing blacks towards insulin resistance.

Metabolic Responses to Exercise

A strong body of research has shown that extended periods of exercise training induce metabolic adaptations that counter insulin resistance (11, 59, 74). These long-term adaptations are quickly reversed with even short periods of detraining however, and it is the response to individual bouts of exercise that accounts for the majority of the improvement reported in insulin sensitivity (28, 45). This single “dose” of exercise (one bout) has a beneficial effect on insulin action that can last up to 2-3 days (58). Heath *et al* (45) concluded the residual effects of one bout of exercise accounted for a 40% improvement in insulin response to glucose in trained white individuals. In an obese, insulin-resistant, predominantly white cohort, Devlin *et al* (28) reported a significant improvement in insulin sensitivity (~25%) after one bout of high-intensity exercise. Hasson *et al* assessed insulin resistance in ten sedentary, overweight/obese African-American women during a sedentary and exercise condition over a two-day period (43). During the sedentary condition, participants fasted overnight and sat quietly in the laboratory for 75 minutes. During the exercise condition, participants completed 75

minutes of brisk walking on a treadmill. Ninety minutes following each condition, participants completed an oral glucose tolerance test (OGTT). The insulin response to the OGTT was 17% lower and insulin sensitivity was 18% higher in the exercise condition compared to the sedentary condition. The effect of exercise to enhance insulin action was smaller compared to both Heath (45) and Devlin *et al* (28) who used predominantly white cohorts. Although there was no direct comparison with whites in this study, these data may provide some clues about possible ethnic/racial differences in the metabolic response to exercise.

Chitwood *et al* (22) conducted the only study to date that directly compared metabolic responses to individual bouts of exercise in blacks and whites. Healthy, lean black and white females of similar age, fitness and family history of obesity completed one bout of 30 minutes of exercise at 65% $\text{VO}_{2\text{max}}$. Insulin, glucose, and serum free-fatty acid concentrations were assessed during rest, exercise and recovery to examine metabolic differences between groups. No significant differences were observed for blood glucose concentrations or serum free fatty acids however, black women displayed higher insulin concentrations at all time points. Although measures of insulin sensitivity were not assessed, this study provides evidence in support of an ethnic/racial difference in the metabolic response to individual bouts of exercise.

Insulin resistance also affects exercise substrate utilization, sparing muscle glycogen and shifting substrate oxidation toward less carbohydrate use. Furthermore, these changes in carbohydrate utilization are independent of differences in body fatness (15). Previous research has shown that, compared with lean men and women, obese individuals use more lipid during exercise at the same relative intensity (56). Braun *et al*

(15) hypothesized that these effects were due to insulin resistance rather than obesity per se and assessed substrate utilization during one bout of moderate intensity exercise in twelve women who were overweight and sedentary but otherwise healthy. The degree of insulin resistance was estimated during an OGTT using the Composite Insulin Sensitivity Index, C-ISI (63). The women were divided into two distinct groups based on similar BMI, percent body fat and VO_{2max} but differing C-ISI scores. Blood glucose uptake (Rd), total carbohydrate/lipid oxidation and estimated muscle glycogen use (EMGU) were assessed using stable isotope dilution and indirect calorimetry during 50 minutes of treadmill walking at 45% VO_{2max} . Insulin resistance shifted substrate use during exercise away from muscle glycogen (EMGU) and toward increased fat oxidation. These results demonstrate that, independent of obesity, insulin resistance alters muscle glycogen and fat use during exercise. Since blacks are, on average, more insulin resistant than whites even when body fat is accounted for, it is likely that exercise substrate use is altered in black individuals relative to their white counterparts. No study to date has directly compared the effects of individual bouts of exercise on insulin sensitivity and metabolic flexibility in substrate use between blacks and whites.

Psychosocial Determinants of Exercise

Despite the benefits of physical activity, more than half of adults in the United States are not regularly active at the recommended levels with minority populations reporting the highest prevalence of leisure-time physical inactivity (21). According to the Centers for Disease Control, physical inactivity is lowest in white men (18.4%). Among black men the prevalence of physical inactivity is 27.0% and black women (33.9%) are also more physically inactive compared to white women (21.6%) (21).

Social Cognitive Theory (6) has been used extensively to explain and influence exercise behavior. Bandura characterizes human behavior as the bi-directional interaction between cognition, behavior and environment, which operates interactively to influence current and future behavior (6). Social cognitive variables, which include self-regulatory exercise self-efficacy, social support for exercise, outcome expectations and perceived barriers, are important predictors of exercise behavior in the general population (6). For example, if an individual reports higher levels of self-regulatory exercise self-efficacy (confidence in their ability to exercise on a regular basis) or more social support for exercise (tasks or steps that significant others take to facilitate an exercise behavior), these variables can influence exercise behavior and result in increased participation in physical activity (6). Additionally, individuals who report changes in psychosocial variables (e.g., post-intervention improvements in self-regulatory exercise self-efficacy and outcome expectations) are also predicted to increase their exercise behavior (6).

Self-efficacy is one of the most widely studied psychosocial correlates of physical activity for the general population. However, there are few studies that have assessed this construct in ethnically diverse populations. Studies that have compared self-regulatory exercise self-efficacy in ethnic minorities have surprisingly reported greater than or equal levels of self-efficacy in blacks as compared to whites despite their decreased participation in leisure-time physical activity (3, 35, 89, 92, 93). Specifically, Wilbur *et al* (93) conducted an intervention, which included 153 middle-aged black and white women. Self-regulatory exercise self-efficacy was assessed before and after participating in a moderate-intensity 24-week home-based walking program. Results demonstrated that ethnicity and pre-intervention self-efficacy scores had positive independent effects on

adherence. Furthermore, adherence was significantly higher for white women compared to black women.

Social support, defined as tasks or steps that significant others take to facilitate behavior, is another determinant of physical activity behavior. Individuals with low levels of physical activity social support are more likely to be sedentary, even when marital status, age, income and education are considered (6). The US Women's Determinants Study examined the association of physical activity-related social support on several measures of physical activity in a national sample of ethnically-diverse women. Latina, Black, and American Indian/Alaskan Native women over age 40 were the focus of this study. A sample of non-Hispanic white women was also surveyed for comparison purposes. Using the physical activity-related social support (PASS) questionnaire in a cohort of 2,912 women, results demonstrated a significant difference among ethnic/racial groups for the total PASS score, family PASS and friends PASS (33). For the friend PASS score, black women (48%) had a significantly higher percentage in the high PASS category than white women (39%). These results suggest social support for physical activity does not necessarily translate into exercise adherence. There were no differences in regular exercise participation among the different amounts of physical activity related social support reported. Specifically, black participants reported low levels of exercise despite high levels of social support. It is possible that social support specific to physical activity may only provide the initial motivation to increase physical activity. Once a regular routine of exercise is established, individuals may no longer rely on external motivating factors to continue their behavior. Blacks may rely on the social support from

others to initiate a new behavior such as exercise, the role of social support may shift, as this behavior becomes a habit.

Whereas blacks tend to overestimate their level of self-regulatory exercise self-efficacy (3, 35, 89, 92, 93), and report higher levels of social support for exercise compared to whites (33, 35), positive changes in psychosocial determinants for exercise increase exercise behavior in both races (6, 7).

Outcome expectations for physical activity also help to explain why individuals initiate or maintain physical activity patterns. This psychosocial variable is defined as a judgement of the consequences of performing a given task (17). Bungum *et al* (17) identified “weight control” as the most frequently cited reason for increasing physical activity behavior in whites (21.7%), however this was the second most cited reason, behind “feeling better” among blacks (21.4% vs. 22.3%, respectively). Even though the order of reasons for increasing one’s physical activity was not identical across ethnic groups, this study suggests that blacks and whites generally report similar rationales for increasing their participation in physical activity.

Personal and environmental barriers are another important determinant of physical activity. This variable refers to obstacles (e.g., lack of time, boredom or lack of enjoyment) that people think are insurmountable, which prevent them from participating in an exercise task (6). King *et al* reported in whites that “lack of time”, “caregiving duties” and “lacking energy” were the top three respective barriers to physical activity (57). In blacks, “lack of safe place to exercise”, “lack of energy” and “caregiving duties” were the top three respective barriers.

In summary, blacks appear to be aware of the benefits associated with habitual exercise (50), leading to increased adoption of exercise in this ethnic/racial group; however this knowledge is not necessarily translating into adherence to an exercise program. Because psychosocial determinants of exercise behavior do not appear to inhibit the adoption of physical activity in blacks; future research should target psychosocial outcomes for exercise to increase adherence to an exercise program.

Psychosocial Outcomes to Exercise

The psychological benefits of regular physical activity are well-documented (19, 88). Multiple reviews and meta-analyses have convincingly reported that exercise has a beneficial effect on depression (70, 84), anxiety (60, 84), and cognitive functioning (e.g., executive control processes) (68). Furthermore, acute bouts of exercise are associated with improved mood (5, 25, 26), decreased state-anxiety (60), and improved exercise task self-efficacy (57). Petruzzello *et al* (60) examined the effect of treadmill running at 75% VO_{2max} for short (15 minutes) and longer durations (30 minutes) on state anxiety and affect scores. The results indicated that state anxiety was reduced equally for both durations of exercise and 30 minutes of running reduced negative affect. Rudolph *et al* (80) investigated the effect of 10, 15, and 20 minute bouts of treadmill running on affect scores at moderate intensity. All participants reported increased positive well-being and decreased psychological distress in all three conditions from baseline to 20 minutes after exercise. Finally, Daley *et al* (27) compared the effect of 15 minutes versus a 30 minute bout of exercise on individuals' affect scores both during and after exercise. Positive affective responses were reported after both the 15 and 30-minute exercise bout and these effects were still evident two hours post-exercise.

Only recently has there been any systematic investigation into the responses during a bout of exercise. This time frame is potentially very important for understanding the temporal dynamics associated with in-task mood responses to exercise. It is possible that affect experienced during an exercise bout can be quite different from the affective change reported from before and after exercise. If a person does not feel well during an exercise bout, even if he/she feels better afterward, he/she might be less inclined to continue the activity. The post-exercise positive feelings might not be sufficient to “override” the negative feelings during exercise. Focht *et al* examined the psychological responses to an acute bout of aerobic exercise in sedentary older and younger adults. Eighteen young (mean age 24 years) and 15 older adults (mean age 64 years) completed a 20-min bout of stationary cycling at 65% of VO_{2max} . In-task mood responses were assessed before, during, and immediately after exercise. Participants' exercise self-efficacy beliefs were assessed before and immediately after exercise. Both groups reported reduced pleasant feeling states and exercise task self-efficacy and increased physical exhaustion in response to individual bouts of exercise. Older adults also demonstrated a significant decrease in revitalization during and after cycling. Correlation analyses revealed that self-efficacy was related to feelings of fatigue during and after exercise as well as postexercise feelings of energy. Both groups reported negative shifts in affect and self-efficacy during and 5 min after cycling (36).

To date, only one study has investigated ethnic/racial differences in anxiety responses to an acute bout of exercise. Marquez *et al* (62) manipulated exercise task self-efficacy and examined its effect on the state anxiety of low active women. The sample consisted primarily of Latina women ($n = 31$) and non-Latina whites ($n = 24$).

Participants were randomly assigned to a low or high efficacy condition, and self-efficacy was manipulated by presentation of computer-generated false feedback after a graded exercise test. Efficacy was successfully manipulated and participants in the high efficacy condition reported significantly less anxiety than those in the low efficacy condition both after the graded exercise test and before and after an acute bout of exercise. Additionally, Latina women were less anxious at all time points of an individual bouts of exercise bout. More research is warranted that examines potential differences psychosocial outcomes among non-Hispanic blacks and whites.

It is predicted that significant improvements in psychosocial outcomes can result in increased adherence to an exercise program (6). Ethnic/racial differences in psychosocial outcomes could explain the lower adherence to an exercise program and lower levels of habitual physical activity. If ethnic/racial differences are present in psychosocial outcomes, future research should target factors such as mood, state-anxiety and exercise task self-efficacy by providing more and better information regarding the benefits of exercise and/or using different strategies to increase adoption and adherence.

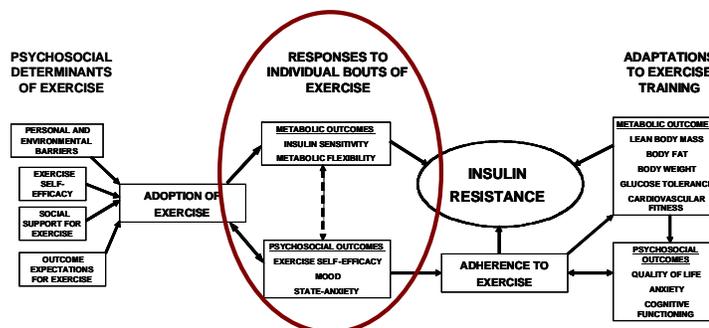
Summary

Blacks may be at higher risk for diabetes compared to whites because they are doing less physical activity or responding differently to the same physical activity stimulus. If blacks are doing less physical activity, it is not likely not that ethnic/racial disparities in psychosocial determinants of exercise behavior play a significant role because positive changes in psychosocial determinants for exercise increase exercise behavior in both races (6, 7, 62). Therefore, differences in physical activity behavior may be more related to ethnic/racial differences in psychosocial outcomes for exercise, which

in turn, likely impact exercise adherence. To date, no study has addressed this important question. Furthermore, there are no obvious ethnic/racial differences in the metabolic response to exercise training. Data from the Diabetes Prevention Program (DPP) (59) and the HHealth, RIsk factors, exercise Training and GENetics (HERITAGE) Family study (11) recruited ethnically diverse subject populations and reported improvements in insulin sensitivity and risk for Type 2 diabetes, regardless of ethnicity/race. As mentioned previously however, it is individual bouts of exercise, not training per se, that play the largest role in attenuating insulin resistance (28, 43).

In summary, psychosocial determinants do not appear to explain the high rates of physical inactivity which may in part contribute to the increased prevalence of insulin resistance reported in blacks; in fact it suggests the opposite. Additionally, there is no evidence that adaptations to exercise training explain the higher rates of insulin resistance in blacks. Therefore, the focus of this dissertation project will center on metabolic and psychosocial outcomes of individual bouts of exercise (illustrated by the highlighted oval in the theoretical model below) because maximizing these responses can have an independent effect to reduce insulin resistance. To our knowledge this is the first study that will assess the contribution of metabolic and psychosocial responses to individual bouts of exercise on insulin resistance in blacks in a systematic manner.

Figure 3: Metabolic and Psychosocial Determinants and Outcomes to Acute and Chronic Exercise: A Theoretical Model Revisited.

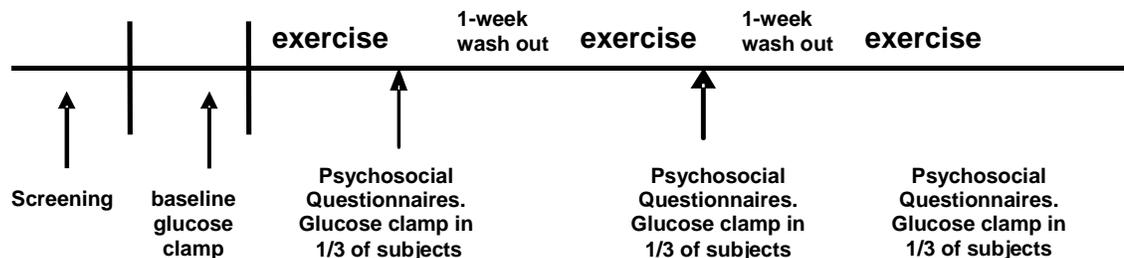


CHAPTER III

METHODOLOGY

The primary objective of this proposal was to compare the metabolic and psychosocial responses to individual bouts of exercise, at an intensity and duration corresponding to current Institute of Medicine guidelines (1), in blacks and age/gender/BMI-matched whites. To accomplish this objective, insulin sensitivity (hyperinsulinemic-euglycemic clamp), metabolic flexibility (an increased in insulin-stimulated carbohydrate disposal and suppression of fat oxidation) and several psychosocial outcomes for exercise (e.g. exercise task self-efficacy, mood, and state-anxiety) were assessed before and after a bout of exercise in black and white men and women (Aim 1). In addition, in-task mood and Rating of Perceived Exertion (RPE) were assessed during exercise. Other variables that could impact the response to exercise (e.g. day of the week, time of day, room temperature and humidity, audio/visual stimuli) were controlled. Because so little is currently known regarding the cumulative response to single bouts of exercise these measurements were repeated three times under the same set of controlled conditions (Aim 2). A schematic overview of the study design is shown in Figure 4.

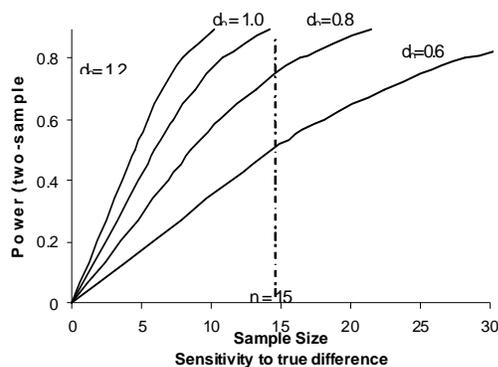
Figure 4. Proposed Study Protocol



Power and Sample Size Analysis

Metabolic measures: The appropriate sample size required to test for statistically significant differences in the response between group means was calculated based on the mean differences and intra-individual variances from a study in which the response to individual bouts of exercise was assessed in black women (17% increase) (43) as compared with Heath and Devlin *et al* (28, 45) data showing changes ranging between 25 and 40% in white men and women. Based on those results, we assumed a 15% difference between the two group means (i.e. between the black and white subjects) in the proposed study, Since the proposed comparisons are between groups, the power calculations are based on a two-sample t-test (alpha level 0.05) of the two-sided null hypothesis that the difference between the group means is zero. The figure below describes a sensitivity analysis that considers the effect of different values of true mean difference (d_0) and sample size (n). The array of curves represents mean differences greater or less than the expected difference (based on the representative study). As shown in the Figure 3, it is anticipated that a study population of 15 subjects per group will have 80% power to detect an ethnic/racial difference in the response to individual bouts of exercise.

Figure 5. Power and Sample Size Estimation



Psychosocial measures: Because there are so few studies in which ethnic/racial differences in the psychosocial response to individual bouts of exercise have been assessed, calculating an appropriate sample size to minimize the probability of Type-2 error is problematic. There are almost no prior data from which to estimate effect sizes based on group mean differences and variability. Using a vastly different study design, Marquez *et al* (62) reported significant differences in self-efficacy with 30 subjects per group. It is likely that the current proposal is not sufficiently powered on ALL of the psychosocial outcome measures to detect statistical significance when differences between group means are subtle. Time and budget limit the scope of this dissertation; however the results of this will guide hypotheses to be tested in future projects which will be larger and more comprehensive. In that regard, the effect sizes noted between groups for the psychosocial outcomes, as well as the direct assessment of the cumulative effect of exercise garnered by repeating the measurements three times under controlled conditions, will provide valuable information even when differences are not significant as defined by $p < 0.05$.

Study Participants

To minimize differences in level of education and neighborhood safety, access to facilities, and lack of transportation, college students and faculty from the University of Massachusetts were recruited to participate in this study. Individuals who were interested in participating in the proposed study were screened to determine eligibility (informed consent, Physical Activity Readiness Questionnaire [PAR-Q], Medical History, and Physical Activity Rating Questionnaire). All participants belonged to one of two ethnic/racial groups: non-Hispanic white or black. Ethnicity/race was defined as persons

who self-identify themselves as belonging to either the black or white race and have resided in the United States for the past 5 years. Thirty-one overweight/obese (BMI = 25-35 kg·m⁻²), sedentary men and women (distributed evenly across ethnicity/race and gender), ages 18-45, were recruited to participate in this study. Sedentary was defined as exercising less than 60 minutes of moderate to vigorous intensity activity per week assessed by questionnaire. All participants were normotensive (SBP 90-135 mmHg, DBP 50-90 mmHg) and non-smokers. Individuals were excluded from this study if they were using medication or supplements known to alter glucose metabolism, reported using dietary interventions to alter body weight in the past 6 months, or were diagnosed with a metabolic or cardiorespiratory disease.

Experimental Design

Baseline Data

An assessment of total daily energy expenditure, resting blood pressure, aerobic fitness, and body composition were completed in addition to answering questionnaires evaluating habitual physical activity and exercise behavior. Each variable is described below in the order in which they were measured.

Estimated Total Daily Energy Expenditure (TDEE): Resting energy expenditure (REE) was measured the morning after an overnight fast using indirect calorimetry with a metabolic cart (ParvoMedics TrueMax 2400, Consentius Technology, Sandy, UT). Participants lied supine and rested quietly for 30 minutes followed by a collection of respiratory gases for 30 minutes using a ventilated hood system. TDEE was estimated by multiplying REE by an activity factor (1.2-1.4) (75).

Body Composition: Fat mass, fat-free mass, percent body fat, and percent trunk fat were assessed via Dual Energy X-ray Absorptiometry (DEXA) (Lunar Prodigy, GE LUNAR Corp., Madison WI). In order to determine truncal fat mass in this study, a quadrilateral box was manually drawn around the axial skeleton of interest (abdomen) from the DEXA scan using bony landmarks extending from the first floating rib to the superior iliac crest.

Psychological Factors: Psychosocial determinants assessed in this study were used to describe and characterize the study population. To study the psychosocial determinants and outcomes of exercise, Social Cognitive Theory (6), developed from Social Learning Theory, was employed. As previously stated, SCT is a theoretical framework extensively used in the study of physical activity behavior. It offers a comprehensive framework for understanding and describing health behaviors and changing them. Self-efficacy is the main construct of SCT. Other determinants of SCT include outcome expectations and personal/environmental barriers. Participants completed questionnaires that assessed their perceptions of physical activity and participation in exercise. Specifically, these questionnaires assessed psychosocial determinants of exercise behavior, which included: self-regulatory exercise self-efficacy, social support for exercise, outcome expectations for exercise and perceived barriers to exercise.

Habitual Physical Activity: After completing all questionnaires, an objective measure of physical activity was obtained in a subset of the participant population using accelerometers (Actigraph GT1M, ActiGraph, LLC, Shalimar, FL). An accelerometer was placed on the participant's hip, securely attached by an elastic band. An electronic

pedometer (Omron HJ-112, Omron Healthcare, Inc., Bannockburn, IL) was also worn on the opposite hip to provide feedback to both the investigators and subjects regarding walking behavior of the individual. Both accelerometer and pedometer information were collected for 7 days between visit 1 and visit 2. Activity counts recorded by an accelerometer were downloaded and analyzed using Actigraph software (ActiGraph, LLC, Shalimar, FL). Freedson cut-points were used to determine the total number of minutes spent in light, moderate, and vigorous physical activity (37).

Dietary Control: Because the dietary information collected is of limited utility when collected in small groups of people under free-living conditions, habitual dietary intake was assessed in this study. In order to reduce the confounding effects of energy imbalance on measurements of insulin sensitivity, all participants consumed a standardized meal provided by the investigators prior to pre- and post-intervention blood measurements. The standardized meals consisted of 20% carbohydrate, 20% protein, 60% fat. These meals were composed of commercially prepared frozen entrees and foods were prepared and weighed in the Energy Metabolism laboratory. Participants were provided with guidelines on overall healthful diets and were encouraged to maintain their body weight throughout the duration of the study. Participants were also asked to refrain from alcohol and caffeinated beverages for the 24 hours preceding each blood measurement.

Control for Menstrual Cycle Phase: All women who participated in this study (n=13) were instructed to record the onset and cessation of menses. Although the data are not consistent, some studies show that insulin sensitivity is lower in the luteal phase of the menstrual cycle (14, 29, 87, 95). Given the time frame over which the study took

place (3-4 weeks), it was not possible to test subjects in a single cycle phase. To balance any potential confounding effects of menstrual cyclicity, half of the women began the study in the follicular phase and half in the luteal phase (estimated as onset of menses + 14 days).

Exercise Protocol

The Institute of Medicine (IOM) recommendations for exercise were used as the prescription of exercise in the proposed study (1). Subjects walked on a treadmill at 75% of maximal heart rate. Treadmill speed and grade were adjusted during the first 10 minutes of exercise until the subject reached the desired intensity. Participants walked at this workload for 75 minutes (4 periods of 15 minutes at the predetermined pace interspersed with 5-minutes at 2.0 mph). Each exercise session included a 5-minute warm-up and cool-down period. Energy expenditure was assessed during one 15-minute bout and a heart rate monitor was worn continuously. Immediately following one of the exercise bouts, energy expenditure was assessed during recovery at 60, 90, and 120 minutes postexercise. To assess the cumulative change in psychosocial responses to exercise, this protocol was repeated at the same time of day and same day of the week (excluding weekends) for three consecutive weeks.

Assessment of insulin sensitivity

Baseline measurements (no exercise): On the day of testing, participants arrived at the laboratory in the fasted state (~ 8-10 hours). Indwelling catheters were placed in a superficial vein of each forearm for infusion of a 20% glucose solution (dextrose) and venous blood sampling. Baseline blood samples were then collected for hormones (e.g. insulin, glucose) and metabolites (e.g. free fatty acids, triglycerides, glucose).

Immediately following the background sample, 2 infusions were started using a peristaltic infusion pump (Harvard Apparatus Pump 22, Holliston MA): 1. a primed (250 $\text{mU}\cdot\text{m}^{-2}$) constant infusion ($40 \text{ mU}\cdot\text{m}^{-2}\cdot\text{min}^{-1}$) of insulin diluted in saline containing 3% (v/v) of the subject's own blood; and 2) a variable infusion of a 20% glucose solution in water, adjusted to maintain plasma glucose at approximately $5 \text{ mMol}\cdot\text{L}^{-1}$, and continued for 120 minutes. Blood samples were collected for immediate glucose analysis every 5 minutes and for insulin and other metabolites of interest at 15, 30, 45, 60, 75, 90, 105 and 120 minutes. Expired breath samples were collected during the last 30 minutes of the clamp using the ventilated hood. Following the clamp procedure, catheters were removed once the participants' glucose concentrations reached $80 \text{ mg}\cdot\text{dL}^{-1}$.

Post-exercise: Approximately 12-15 hours following exercise, participants completed a second hyperinsulinemic-euglycemic clamp. All of the procedures were identical to the protocol described above.

Psychosocial outcomes: To assess pre-post changes in psychosocial outcomes for exercise, questionnaires assessing mood, exercise task self-efficacy, and state anxiety were administered before and after each bout of exercise. To assess mood during exercise, participants answered questions during each exercise bout regarding “how do you feel” and “how hard do you feel you are exercising”. Feeling Scale (FS) and Borg's Rating of Perceived Exertion (RPE) were used as measures in-task mood and perceived exercise intensity, respectively. Additionally, heart rate was collected to objectively verify exercise intensity. These measures were taken every five minutes during exercise.

Psychosocial responses to exercise can be influenced by the context in which the exercise takes place (6). To minimize environmental influences on the results obtained,

this protocol was designed to control for the most likely confounding factors. Day of the week (weekends excluded) and time of day were standardized to minimize the influence of day-to-day events on psychosocial responses to exercise. In addition, subjects were not provided with any feedback regarding their physiological state (kilocalories burned, heart rate response during exercise) until they had completed the study. A source of exercise self-efficacy information is emotional arousal. Bandura suggests that emotional arousal or physiological states might affect behavior by altering self-efficacy expectations (6). Individuals may interpret symptoms (e.g., a rapid heart rate) as a sign that they cannot perform the activity safely. Hence, this information could potentially influence psychosocial outcomes for exercise including exercise task self-efficacy, mood, and state-anxiety). Finally, visual and auditory stimuli (e.g. television viewing during exercise) were standardized. The schedule of measurements is presented below.

Table 1. Time Table of Metabolic and Psychosocial Measurements

Measurement	Baseline	Exercise Bout 1			Exercise Bout 2			Exercise Bout 3		
		Pre-	During	Post-	Pre-	During	Post-	Pre-	During	Post-
Task Self-Efficacy		X		X	X		X	X		X
State-Anxiety		X		X	X		X	X		X
Mood		X		X	X		X	X		X
In-Task Mood			X			X			X	
Rating of Perceived Exertion			X			X			X	
Heart Rate			X			X			X	
Metabolic Inflexibility*	X			X			X			X
Insulin Sensitivity*	X			X			X			X

* Post-exercise measurements of insulin sensitivity and metabolic inflexibility will be made once, randomized to one of the three exercise bouts

Analyses

Blood Collection and Biochemical Analysis: Venous blood samples were collected in sterile heparinized syringes and transferred to anticoagulant EDTA for analysis of fatty acids, triglycerides and insulin. Venous blood samples were transferred to tubes containing a glycolytic inhibitor (sodium fluoride and potassium oxalate) for analysis of glucose. Samples were immediately centrifuged at (3,000 × g) for 15 minutes

and plasma was aliquoted into cryotubes and stored at -80°C until analysis. Plasma glucose concentrations were determined by the glucose oxidase method using a GL5 Analox Analyzer (GL5 Analox, Analox Instruments, Lunenburg, MA). Plasma insulin concentrations were determined by radioimmunoassay (Human RIA Kit, Millipore, Inc., St. Charles, MO). Enzymatic kits were used to analyze plasma free fatty acid (Wako Chemicals USA, Richmond, VA) and triglycerides (Sigma Chemical, St. Louis, MO) concentrations.

Metabolic outcomes

Whole-body insulin sensitivity: The primary outcome measure was whole-body insulin sensitivity, defined as the rate of blood glucose uptake (Rd) per unit plasma insulin concentration (steady-state plasma insulin; SSPI). Rate of blood glucose uptake was expressed as the ratio of the amount of glucose metabolized to the prevailing plasma insulin levels [M ($\text{mg} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$)/ I (pMol)] during the last 30 min of the euglycemia.

Oxidative and non-oxidative glucose disposal (NOGD): Glucose oxidation was calculated from measurements of VCO_2 and VO_2 during indirect calorimetry. NOGD (assumed to be glucose storage as muscle glycogen) was calculated as (glucose rate of disappearance) – (rate of carbohydrate oxidation).

Metabolic flexibility: Whole-body carbohydrate and fat oxidation rates during the post-exercise resting period and during the hyperinsulinemic-euglycemic clamp were calculated using indirect calorimetry. In participants with “normal” insulin sensitivity, the elevated insulin concentrations during the glucose clamp cause an abrupt “switch” from primarily fat oxidation (rest) to primarily carbohydrate oxidation (clamp). The magnitude of the switch (Δ fat oxidation and Δ carbohydrate oxidation) was used as an index of

metabolic flexibility. Substrate oxidation was calculated from VO_2 and CO_2 ($\text{L}\cdot\text{min}^{-1}$) using the formulas of Peronnet and Massicotte(76): Fat oxidation rate = $1.6946 \text{VO}_2 - 1.7012 \text{VCO}_2$, Carbohydrate oxidation rate = $4.5850 \text{VCO}_2 - 3.2255 \text{VO}_2$, and Respiratory Exchange Ratio = VCO_2/VO_2 .

Psychosocial Determinants

The current study focused on those social cognitive variables demonstrated to be most influential for blacks and whites based upon several narrative reviews (32, 34, 83, 88). Again, psychosocial determinants assessed in this application were only used to describe and characterize the study population.

The **Exercise Self-Efficacy Scale** (64) assessed an individual's beliefs in their ability to exercise on a four-time per week basis at moderate intensities for 30 minutes or more per session for six months. A self-efficacy score was calculated by summing the confidence ratings and dividing by the total number of items in the scale, resulting in a maximum possible efficacy score of 100. Support has been established for the internal consistence of the Exercise Self-Efficacy Scale (alpha coefficient of .95) and its validity (66, 67).

The **Social Support and Exercise Scale (SSES)** (82) measured social support specifically related to exercise habits. The 13-item scale assessed social support from friends and family, respectively, during the last three months. SSES scores were broken down into Family Participation, Family Rewards and Punishment, and Friend Participation subscales. The SSES has demonstrated adequate validity and reliability (13, 78).

The **Outcome Expectations for Exercise (OEE) Scale** (79) was developed based upon Bandura's theory of self-efficacy and contains nine items assessing the extent to which one believes that engaging in exercise will result in specific outcomes. Responses were made on a 5-point Likert scale (1 = strongly agree to 5 = strongly disagree). The responses to all nine items were then summed with a possible range of 9-45, in which lower scores are related to greater outcome expectations. Support has been established for the internal consistency of the OEE scale (alpha coefficient of .89) and for its validity; i.e. those who exercised regularly had lower OEE scores than those who did not.

The **Exercise Barriers questionnaire** (57) consists of 10 often-reported personal barriers to exercise and physical activity, including lack of time and feeling too tired to exercise. The frequency with which each barrier occurred was rated on a 5-point scale (1 = never to 5 = very often). Several items were added to the scale, which represent common exercise barriers reported by ethnic/racial minorities in the United States (e.g., lack of transportation and lack of facilities).

Psychosocial Outcomes

The **Exercise Self-Efficacy Scale for Duration** assessed individual's beliefs in their ability to walk at a moderate intensity without stopping. The scale consisted of six items, with each item representing one 10-minute increment. For each item on the scale, participants were asked to indicate how confident they were that they could successfully carry out the specific activity. The responses were scored on a 100-point percentage scale (100% = complete confidence, 0% = no confidence at all). A summary self-efficacy score was calculated by summing the confidence ratings and dividing by the total number of items in the scale, resulting in a maximum possible self-efficacy score of 100. This scale

has been shown to be valid and reliable in the general population, including ethnic/racial minorities (51, 62).

The **State Trait Anxiety Inventory (STAI)** (86) is the definitive instrument for measuring anxiety in adults. The STAI has 20 questions with four possible responses to each. The items were summed to produce a total score in which higher scores equate to greater state anxiety. The STAI has been shown to be valid and reliable (90).

To evaluate pre- and post- exercise changes in mood, participants were asked to complete the **Subjective Exercise Experiences Scale (SEES)** (65). The SEES is a 12-item, three-dimensional scale that assessed three general categories of affective responses to exercise: positive well being (e.g., great), psychological distress (e.g. miserable), and fatigue (e.g., tired). For each item participants were asked to indicate how strongly they were experiencing the feeling state at that time. Items were scored on a 7-point Likert scale, with scores from each subscale ranging from “not at all” (1) and “very much so”. Each sub-scale ranges from 4 to 28 with a higher score representing greater fatigue, positive well-being or distress. The SEES has been shown to have a high internal consistency across a variety of populations (65).

To evaluate mood responses during acute bouts of exercise, **Feeling Scale** (27, 80) was employed. Every five minutes during the exercise participants were asked, “How you feel right now”? Participants responded by selecting from an eleven-point scale, ranging from -5 (‘I felt very bad’) through neutral to +5 (‘I felt very good’).

To determine **Rating of Perceived Exertion (RPE)** (10), participants responded by selecting from a fifteen-point scale ranging from 6 (‘no exertion at all’) to 20 (‘maximal exertion’). Responses to feeling state, RPE and heart rate measures were

averaged across each day of the exercise intervention to arrive at a mean affective response.

Statistical Analysis

Ethnic/racial differences in baseline measurements (resting metabolic rate, resting blood pressure, percentage of total and truncal fat, fat free mass, exercise self-regulatory self-efficacy, social support for exercise, outcome expectations, perceived barriers, socioeconomic status, circulating free fatty acid and triglycerides concentrations, fasting fat oxidation, whole-body insulin sensitivity, oxidative and non-oxidative glucose disposal) were assessed with standard summary statistics and compared using two-sample t-test, controlled for multiple testing as appropriate.

It was hypothesized that the positive metabolic effects of exercise on whole-body insulin sensitivity would be smaller in blacks compared to whites. Therefore, a two-way repeated measures ANOVA was used to assess post-exercise changes in the metabolic outcomes (main effects: ethnicity/race and treatment; interaction: ethnicity/race x treatment). It was hypothesized that the positive psychosocial effects on exercise task self-efficacy, state-anxiety, and mood after each bout of exercise would be smaller in blacks compared to whites. Therefore, a three-factor repeated measure ANOVA was implemented to assess post-exercise changes in psychosocial outcomes (main effects: ethnicity/race by treatment by time; interactions: ethnicity/race x treatment and ethnicity/race x time).

Interpretations

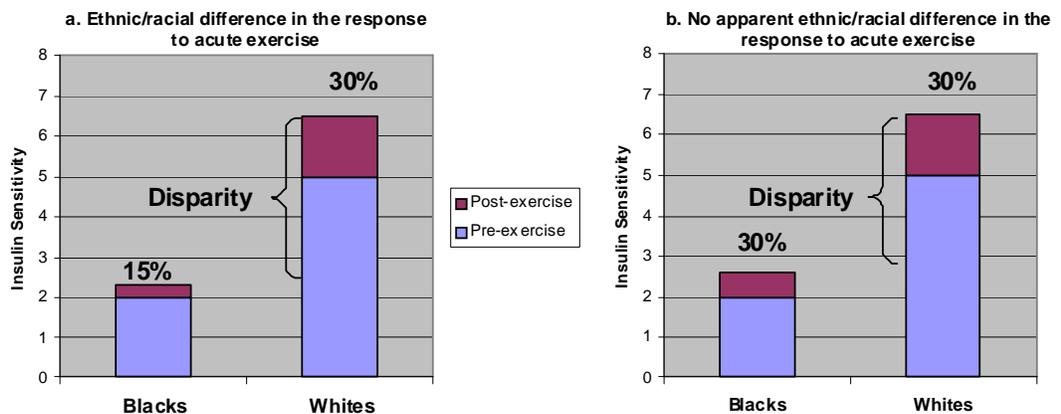
The key hypotheses for this study focus on whether there is an ethnic/racial difference in metabolic and psychosocial responses to individual bouts of exercise. The

results of this study will provide insight regarding how overweight, sedentary but otherwise healthy blacks respond to an exercise stimulus compared to their white counterparts.

Aim 1: Metabolic outcomes: If insulin sensitivity and/or the suppression of fat oxidation during the glucose clamp are LESS enhanced after exercise in black individuals, the implication is that the metabolic response to exercise is less robust and may contribute to the higher rates of insulin resistance reported in blacks compared to whites.

If there are different metabolic responses to exercise in blacks, it may be appropriate to evaluate the utility of more specific exercise recommendations. Practitioners/clinicians may need to craft exercise prescriptions specifically designed to reduce insulin resistance in blacks. If an ethnic/racial difference in the response to exercise is found, future research will need to determine the appropriate intensity, duration, and frequency of exercise required to reduce the disparity reported in diabetes risk in this ethnic minority population (see Figure 5a).

Figure 6. Possible Outcomes to Individual bouts of exercise in Blacks and Whites.



It is also possible that the response to exercise in black participants is equal to or even accentuated compared to white participants. How these different outcomes could potentially impact the ethnic/racial disparity in risk for Type-2 diabetes depends on both the change in relative risk and the change in absolute risk. Assuming that black individuals have more insulin resistance at baseline, the same percentage enhancement of insulin sensitivity by exercise in black and white participants still leaves the black individuals with lower insulin sensitivity (see figure b) and an increased risk for Type 2 diabetes.

Psychosocial Outcomes: Acute changes in physical activity can influence psychosocial outcomes such as exercise task self-efficacy (57), state anxiety (60) and mood (5, 25, 26). Smaller improvements in psychosocial outcomes could result in lower adherence to exercise programs and lower levels of habitual physical activity. Based on the evidence that blacks report a lower adherence to exercise programs compared to whites (93), it was hypothesized that blacks will demonstrate smaller improvements in psychosocial outcomes for exercise compared to whites. If ethnic/racial differences are present in psychosocial outcomes, future research should target factors such as mood, barriers to exercise and exercise task self-efficacy by providing more and better information regarding the benefits of exercise and/or using different strategies to increase adoption and adherence to exercise programs. For example, if black participants demonstrate a peak affective state at 30 minutes but white participants reach a peak at 60 minutes, the exercise recommendations (e.g. 30- vs. 60-minutes, continuous vs. intermittent) that will achieve maximal adherence might be race specific. If blacks demonstrate similar improvements in psychosocial outcomes for exercise, future research

should examine the influence of other personal and environmental constructs of Social Cognitive Theory (6) (e.g., exercise enjoyment, perceived health status, perceived neighborhood safety, lack of transportation, etc.) on exercise behavior in this ethnic/racial minority group.

Aim 2: Information on the cumulative effect of individual bouts of exercise on psychosocial responses can guide future training studies assessing exercise effects on psychosocial outcomes. Since so little is currently known regarding ethnic/racial differences in the psychosocial response to individual bouts of exercise, the results from this study will be extremely useful to generate the most urgent hypotheses to be addressed in larger-scale clinical trials.

Pilot Study

To gain information about the procedures that were used in this dissertation study, pilot data were first collected in two normoglycemic, normal weight, but currently-inactive women.

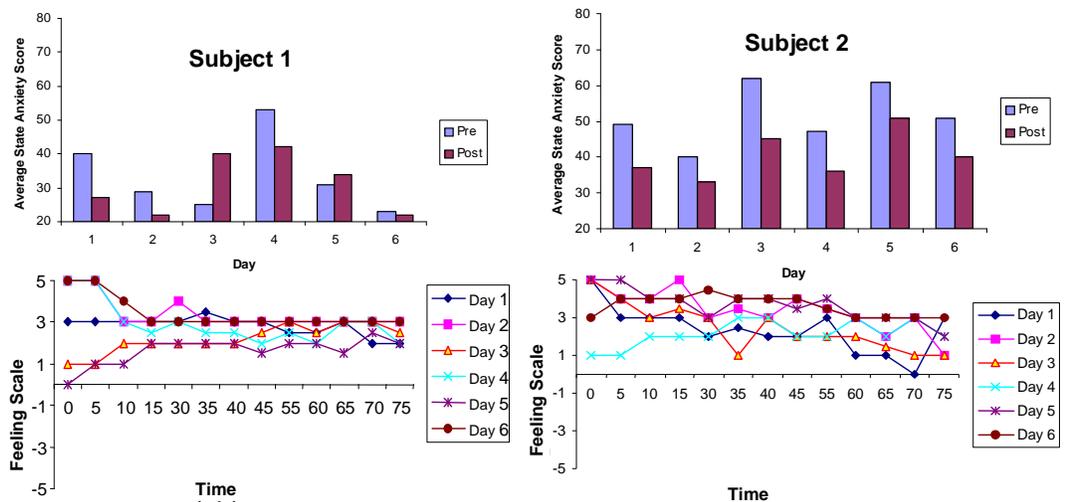
Table 2. Pilot Study Subject Characteristics

Subject Characteristics					
Age (years)	Gender	Ethnicity	BMI (kg/m ²)	Physical Activity	Family History
27	Female	Black	22	Currently Inactive	Positive
31	Female	Hispanic- White	23.4	Currently Inactive	Positive

Participants came to the energy metabolism laboratory and completed 75 minutes of exercise, walking at 60% VO_{2max} (~75% HR_{max}) for six consecutive days. The 75 minutes of exercise consisted of 4 bouts of 15 minutes of walking at the prescribed pace interspersed by 5-minute bouts at a self-selected pace. Pre-post exercise changes in psychosocial outcomes were assessed via questionnaires measuring mood, exercise task self-efficacy, and state anxiety. Feeling state and rating of perceived exertion were

measured every 5 minutes during each exercise bout. State-anxiety, mood, and feeling state varied considerably when assessed during exercise (see Figure 6). It appeared that the pre-exercise values exerted some influence on the response to exercise. These results led us to the controlled study environment designed to minimize as many as variables as possible that could impact pre-exercise state-anxiety, mood and feeling state (e.g. time of day, weekday vs. weekend, audio/visual stimuli and climate conditions). Additionally, these results led to the second aim of this dissertation project of assessing the cumulative effect of individual bouts of exercise on psychosocial outcomes.

Figure 7. Psychosocial Responses to Individual bouts of exercise



Summary

The design of this dissertation project examined the metabolic and psychosocial factors that contribute to the increased prevalence of insulin resistance and low adherence to exercise programs in black populations. It was recognized that changes in habitual behavior are warranted to counteract a cultural climate or genetic predisposition that puts blacks at an increased risk for Type 2 diabetes. Therefore, it was necessary to identify

and target genuine and perceived barriers that prevent blacks from changing their exercise behavior.

CHAPTER IV

**ETHNIC/RACIAL DIFFERENCES IN THE EFFECTS OF INDIVIDUAL BOUTS
OF EXERCISE ON INSULIN SENSITIVITY**

**Rebecca Hasson
Kirsten Granados
Stuart Chipkin
Patty Freedson
Barry Braun**

University of Massachusetts, Amherst Department of Kinesiology

**Corresponding author: Barry Braun
University of Massachusetts
Department of Kinesiology
Totman Building
Amherst, MA 01003**

Phone: (413) 545-1337

FAX: (413) 545-2906

Email: bbraun@kin.umass.edu

Running Title:

Abstract

INTRODUCTION: Non-Hispanic blacks (blacks) are more insulin resistant than non-Hispanic whites (whites). Ethnic/racial disparities in the response to exercise may contribute to the differences reported in insulin resistance. Because the beneficial effects of exercise are transient, single exercise bouts have strong implications for opposing insulin resistance. **PURPOSE:** The purpose of this study was to compare metabolic responses to a single bout of exercise in blacks (n = 11) and age/gender/BMI-matched whites (n = 10). **METHODS:** Insulin sensitivity, non-oxidative glucose disposal, and metabolic flexibility in substrate use were assessed during a hyperinsulinemic-euglycemic clamp and indirect calorimetry in sedentary black and white participants. Outcome measures were evaluated at baseline and 12 hours after participants walked on a treadmill at 75% of maximum heart rate for 75 minutes. **RESULTS:** There were no differences in baseline measures of insulin sensitivity between blacks and whites (0.099 ± 0.02 vs. 0.098 ± 0.02 [(mg/kg/min)/pMol], respectively). There were no ethnic/racial differences in fasting fat oxidation however blacks had significantly higher insulin-stimulated carbohydrate oxidation compared to whites. Insulin sensitivity increased after exercise in blacks (+18%) but not whites (-1.8%), however this improvement was not statistically significant ($p = 0.50$). Non-oxidative glucose disposal (storage) was significantly higher in whites at baseline ($p = 0.04$). After exercise, there was a trend towards increased glucose storage in blacks compared to whites (+19.6% vs. +3.3%; $p = 0.09$). **CONCLUSIONS:** These data suggest there are no ethnic/racial differences in the insulin sensitivity response to individual bouts of exercise. However, blacks had a greater capacity to enhance insulin stimulated glucose oxidation during compared to whites. One bout of exercise may improve non-oxidative glucose disposal in blacks to comparable levels in whites. This study provides evidence in support of using exercise to enhance glucose metabolism and reduce risk of Type 2 diabetes in blacks.

Introduction

The prevalence of Type 2 diabetes is increasing at epidemic rates and the risk for non-Hispanic blacks (blacks) is two-fold higher than for non-Hispanic whites (whites) (12, 20, 47). This ethnic/racial disparity in diabetes prevalence is associated with more severe insulin resistance (38, 39, 41, 71). Insulin resistance is a condition in which muscle, adipose, and liver cells are less sensitive to the metabolic effects of insulin. Physiologic actions of insulin are inhibited but can be compensated for by an increased concentration of blood insulin (i.e., hyperinsulinemia). The underlying mechanisms for increased insulin resistance reported in blacks are unknown however, higher rates of obesity and/or less participation in physical activity likely play a key role (21, 24). Surprisingly, few researchers have successfully matched black and white individuals on these risk factors to assess ethnic/racial differences in insulin resistance (8, 94).

A strong body of research has demonstrated that extended periods of exercise training induce metabolic adaptations that counter insulin resistance (11, 59, 74). These long-term adaptations are quickly reversed with even short periods of detraining, and it is the response to individual bouts of exercise that accounts for the majority of the improvement reported in insulin sensitivity (28, 58). Heath *et al.* (45) detected a 40% improvement in the insulin response to glucose in trained individuals after one bout of exercise. Devlin *et al.* (28) reported a significant improvement in insulin stimulated glucose uptake (~25%) after just one bout of high-intensity exercise in an obese, insulin resistant cohort.

Insulin resistance can however, affect the metabolic response to exercise (16). During exercise, insulin resistant women use less muscle glycogen and oxidize more

lipids compared with insulin sensitive women matched for adiposity (16). Relative to insulin sensitive individuals, men and women who are insulin resistant exhibit lower fat oxidation in the fasted state and do not effectively switch to primarily carbohydrate oxidation in the insulin-stimulated state, a condition that has been termed “metabolic inflexibility”(53-56). Compared to whites, blacks appear to be less metabolically flexible; i.e. a smaller increase in fat oxidation during epinephrine infusions (8). It is possible that substrate oxidation is altered in blacks relative to their white counterparts, which may potentially influence their insulin sensitivity response to exercise. As a result, blacks may respond differently to exercise compared to whites which could be related to the increased insulin resistance reported in blacks. In support of this hypothesis, our laboratory previously reported that one bout of moderate intensity exercise improved insulin sensitivity in black women with insulin-resistance (43), but the effect was smaller than what previous researchers had observed in white cohorts (28, 45). No study to date has directly compared the effects of individual bouts of exercise on insulin sensitivity and metabolic flexibility between blacks and whites. Therefore, the primary aim of this study was to compare the metabolic responses to a single bout of exercise in blacks and age/gender/BMI-matched whites.

Methods

Participants. Eleven black and ten white previously-sedentary but otherwise healthy men and women from the university community participated in this study. All participants belonged to one of two ethnic/racial groups: non-Hispanic black or non-Hispanic white. Ethnicity/race was defined as persons having resided in the United States for the past 5 years who self-identify themselves as belonging to either the black or white

race. Sedentary was defined as having participated in less than 60 minutes of moderate to vigorous intensity activity per week assessed by questionnaire. Participants were free from diagnosed cardiovascular disease, hypertension, diabetes, and any other disease that could affect insulin or glucose responses. Individuals who smoked cigarettes or used pharmacologic agents (e.g., metformin, ACE-Inhibitors, statin drugs,) or dietary supplements (e.g., chromium, ephedra) known or suspected to alter insulin action were excluded. After being provided with a full description of the study, subjects signed an informed consent document approved by the Institutional Review Board at the University of Massachusetts, Amherst.

Baseline Measurements. Before completing the exercise protocol, assessments of total daily energy expenditure and body composition were completed. Each variable is described below in the order in which they were measured.

Total Daily Energy Expenditure (TDEE). Resting energy expenditure (REE) was measured the morning after an overnight fast using indirect calorimetry with a metabolic cart (ParvoMedics TrueMax 2400, Consentius Technology, Sandy, UT). Participants lied in the supine position and rested quietly for 30 minutes after which respiratory gases were collected for 30 minutes using a ventilated hood system. TDEE was estimated by multiplying REE by an activity factor (1.4) (75).

Body Composition. Fat mass, fat-free mass, percent body fat and percent truncal fat were assessed via Dual Energy X-ray Absorptiometry (DEXA) (Lunar Prodigy, GE LUNAR Corp., Madison WI). In the present study, truncal fat mass was calculated by manually drawing a quadrilateral box around the torso from the DEXA scan using bony landmarks extending from the shoulder and pelvic girdle of the axial skeleton. DEXA

scans have been found to be a reliable measure of percent fat, fat mass, and lean tissue mass with precision errors of 1.4%, 1.0 kg, and 0.8 kg, respectively. The radiation exposure from this procedure is negligible and is estimated to be 0.06mR (96).

Participants were scanned while lying flat on their backs with arms by their sides.

Dietary Control: In order to reduce the confounding effects of energy imbalance on measurements of insulin sensitivity, all participants consumed a controlled diet provided by the investigators prior to baseline and post-exercise blood measurements. The standardized meals consisted of 60% fat, 20% carbohydrate, 20% protein. A post-exercise high-fat meal has been shown to elicit larger improvements in insulin sensitivity compared to a post-exercise high-carbohydrate meal (46). These meals were composed of commercially prepared frozen entrees and foods prepared and weighed in the Energy Metabolism laboratory. Subjects were provided with guidelines on overall healthful diets and were encouraged to maintain their body weight throughout the duration of the study. Subjects were also asked to refrain from alcohol and caffeinated beverages for the 24 hours preceding each blood measurement.

Control for Menstrual Cycle Phase: All women participating in this study (n=13) were instructed to record the onset and cessation of menses. Although the data are not consistent, some studies have shown that insulin sensitivity is lower in the luteal phase of the cycle (14, 29, 87, 95). To balance any potential confounding effects of menstrual cyclicity, half of the women began the study in the follicular phase and half in the luteal phase (estimated as onset of menses + 14 days).

Exercise Protocol. The Institute of Medicine (IOM) recommendations for exercise were used as the prescription of exercise in the present study (1). Participants

walked on a treadmill at 75% of maximal heart rate. Treadmill speed and grade were adjusted during the first 15 minutes of exercise until the subject reached the desired intensity and participants walked at that workload for 75 minutes (4 periods of 15 minutes at the predetermined pace interspersed with 5-minutes at a 2.0 mph). Each exercise session included a 5-minute warm-up and cool-down period. Breath samples were taken during one 15-minute bout to calculate exercise energy expenditure. Immediately following exercise, breath samples were taken for 15-minute intervals at 60, 90, and 120 minutes of recovery to assess post-exercise energy expenditure and substrate oxidation using indirect calorimetry with a metabolic cart (ParvoMedics TrueMax 2400, Consentius Technology, Sandy, UT).

Assessment of insulin sensitivity. *Baseline (no exercise.)* On the day of testing, participants arrived at the laboratory in the fasted state (~ 9 hours) and completed an assessment of whole-body insulin sensitivity (hyperinsulinemic-euglycemic clamp). Indwelling catheters were placed in a superficial vein of each forearm for infusion of glucose solution and venous blood sampling. Baseline blood samples were collected for hormones (e.g. insulin, glucose) and metabolites (e.g. free fatty acids, triglycerides, and glucose). Immediately following the background samples, two infusions were started using a peristaltic infusion pump (Harvard Apparatus Pump 22, Holliston MA): 1) a primed ($250 \text{ mU}\cdot\text{m}^{-2}$) constant infusion ($40 \text{ mU}\cdot\text{m}^{-2}\cdot\text{min}^{-1}$) of insulin diluted in saline containing 3% (v/v) of the subject's own blood; and 2) a variable infusion of a 20% glucose solution in water, adjusted to maintain plasma glucose at approximately $5 \text{ mMol}\cdot\text{L}^{-1}$, and continued for 120 minutes. Blood samples were collected for immediate glucose analysis every 5 minutes and for insulin, free fatty acids and triglycerides at 15,

30, 45, 60, 75, 90, 105 and 120 minutes. Expired breath samples were collected during the last 30 minutes of the clamp using the ventilated hood. Following the clamp procedure, catheters were removed.

Post-exercise. Approximately 12-15 hours following exercise, participants completed a second hyperinsulinemic-euglycemic clamp to assess changes in whole-body insulin sensitivity. All of the procedures were identical to the protocol described above.

Analyses. *Blood Collection and Biochemical Analysis.* Venous blood samples were collected in sterile heparinized syringes and transferred to anticoagulant EDTA for analysis of insulin, free fatty acids, and triglycerides. Venous blood samples were transferred to tubes containing a glycolytic inhibitor (sodium fluoride and potassium oxalate) for analysis of glucose. Samples were immediately centrifuged (at $3,000 \times g$) for 15 minutes and plasma was aliquoted into cryotubes and stored at -80°C until analysis. Plasma glucose concentrations were determined by the glucose oxidase method using a GL5 Analox Analyzer (GL5 Analox, Analox Instruments, Lunenburg, MA). Plasma insulin concentrations were determined by radioimmunoassay (Human RIA Kit, Linco Research, Inc., St. Charles, MO) and enzymatic kits were used to analyze plasma free fatty acid (Wako Chemicals USA, Richmond, VA) and triglyceride (Sigma Chemical, St. Louis, MO) concentrations.

Outcome Measures. *Whole-body insulin sensitivity.* The primary outcome measure was whole-body insulin sensitivity, defined as the rate of blood glucose uptake per unit plasma insulin concentration. Rate of blood glucose uptake was expressed as the ratio of the amount of glucose metabolized to the prevailing plasma insulin levels [$\text{M} (\text{mg} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}) / \text{I} (\text{pMol})$] during the last 30 min of the euglycemia.

Oxidative and non-oxidative glucose disposal (NOGD). Glucose oxidation was calculated from measurement of VCO_2 and VO_2 using indirect calorimetry during the last 30 minutes of euglycemia. NOGD (assumed to be glucose storage as muscle glycogen) was calculated as (glucose rate of disappearance) – (rate of carbohydrate oxidation).

Metabolic flexibility. Whole-body carbohydrate and fat oxidation rates measured throughout the entire study were calculated using indirect calorimetry. In subjects with “normal” insulin sensitivity, the elevated insulin concentrations during the glucose clamp cause an abrupt “switch” from primarily fat oxidation (rest) to primarily carbohydrate oxidation (clamp). The magnitude of the switch (Δ fat oxidation and Δ carbohydrate oxidation) was used as an index of metabolic flexibility. Substrate oxidation was calculated from VO_2 and VCO_2 ($L \cdot \text{min}^{-1}$) using the formulas of Peronnet and Massicotte (76): Fat oxidation rate = $1.6946 VO_2 - 1.7012 VCO_2$, Carbohydrate oxidation rate = $4.5850 VCO_2 - 3.2255 VO_2$, and Respiratory Exchange Ratio = VCO_2/VO_2 .

Statistical Analysis. Ethnic/racial differences in baseline measurements (total daily energy expenditure, total and truncal fat percentage, fasting free fatty acid and triglyceride concentrations, fasting fat oxidation, whole-body insulin sensitivity, and insulin-stimulated glucose disposal) were assessed with standard summary statistics and compared using two-sample t-test, controlled for multiple testing when appropriate. It was hypothesized that the positive metabolic effects of exercise on whole-body insulin sensitivity and metabolic flexibility would be smaller in blacks compared to whites. Therefore, a two-way repeated measures ANOVA was used to assess post-exercise changes in insulin sensitivity, insulin-stimulated glucose disposal and metabolic flexibility (main effects: ethnicity/race and treatment; interaction: ethnicity/race x

treatment). A three-way repeated measures ANOVA was used to assess fasting and insulin-stimulated free fatty acid concentrations and post-exercise substrate oxidation (main effects: ethnicity/race by treatment by time; interactions: ethnicity x treatment and ethnicity x time). Tukey's post-hoc analyses were completed to determine which time points were statistically different. Differences between ethnic/racial groups, conditions, and time were considered statistically significant at $\alpha < 0.05$.

Results

Baseline Characteristics. Eleven Non-Hispanic blacks and 10 non-Hispanic whites of similar age, BMI, and physical activity status completed the study protocol. No significant differences were detected between the two groups for any of the baseline physical measures (**Table 3**). All participants were able to complete 75 minutes of brisk walking on the treadmill, during which they expended approximately 480 kilocalories (blacks: 501.7 ± 107.8 , whites: 463.3 ± 136.4). During the final 60 minutes of the Hyperinsulinemic-euglycemic clamp, plasma glucose and insulin concentrations were held constant with glucose concentrations maintained at 5mMol (**Figure 8**).

Fasting glucose, insulin, free fatty acid, triglyceride concentrations, and insulin sensitivity (**Table 4**). There were no significant differences in fasting plasma insulin, free fatty acid and triglyceride concentrations and whole-body insulin sensitivity between black and white participants. However, fasting plasma glucose concentrations however, were significantly lower in blacks compared to whites ($p = 0.01$). Exercise significantly increased fasting plasma free fatty acid concentrations in both black and white participants ($p < 0.001$), with fasting plasma glucose concentrations remaining significantly lower in black participants ($p = 0.01$). Exercise had no significant effect on

fasting plasma insulin and triglyceride concentrations in either group ($p = 0.83$, $p = 0.29$, respectively).

Effects of Exercise on Insulin Sensitivity, Glucose Storage and Free Fatty Acid Concentrations. The insulin sensitivity responses to exercise are shown in **Figure 9**. Insulin sensitivity measured during the Hyperinsulinemic-euglycemic clamp increased after exercise in blacks (+18%) but not whites (-1.8%), however this improvement was not statistically significant ($p = 0.50$).

Insulin-stimulated glucose disposal (glucose storage) was significantly higher in whites compared to blacks at baseline and after exercise ($p = 0.04$). In black participants, there was a trend towards increased glucose storage in response to exercise ($p = 0.09$) however, this improvement did not eliminate ethnic/racial difference in non-oxidative glucose disposal (**Figure 10**).

Compared to fasting conditions, insulin-stimulated plasma free-fatty acid concentrations were significantly lower in both groups during the baseline and post-exercise clamp ($p < 0.0001$), however, insulin-stimulated free-fatty acid concentrations were significantly higher during the post-exercise clamp ($p < 0.0001$).

Metabolic Flexibility. Baseline measures of fasting fat oxidation were similar in both groups ($p = 0.52$) (**Figure 11**). Exercise increased the contribution of calories derived from fat at rest in black and white participants, however this improvement was not statistically significant ($p = 0.10$). Compared to whites, blacks had significantly higher insulin-stimulated carbohydrate oxidation during both baseline ($p = 0.003$) and post-exercise clamps ($p = 0.03$).

Carbohydrate oxidation during exercise was similar in both groups ($p = 0.27$), but post-exercise carbohydrate oxidation was significantly higher in blacks ($p = 0.03$) (**Figure 12**). At two hours post-exercise, black participants expended significantly more carbohydrate kilocalories compared to whites ($p = 0.0008$), and total carbohydrate kilocalories expended during the entire recovery period tended to be higher in blacks ($p = 0.09$) (**Figure 13**).

Discussion

The purpose of this study was to evaluate the metabolic responses to a single bout of exercise in blacks and age/gender/BMI-matched whites. It was hypothesized that the effect of exercise to enhance insulin sensitivity during a hyperinsulinemic-euglycemic clamp would be smaller in blacks compared to whites due to the increased insulin resistance previously-reported in this population. Additionally, exercise would have a smaller effect to enhance fasting fat oxidation and insulin-stimulated carbohydrate oxidation in blacks compared to whites. Contrary to our hypotheses, blacks were more metabolically flexible in substrate use and demonstrated a larger improvement in the insulin sensitivity response to individual bouts of exercise compared to their white counterparts. These data provide evidence in support of an ethnic/racial difference in metabolic flexibility and the insulin sensitivity response to individual bouts of exercise.

It is recognized that a single bout of exercise does not reflect the adaptations seen with chronic (weeks/months) exercise training. A body of research has documented that the majority of the improvements in insulin sensitivity are transient effects of recent exercise and are lost 24-72 hours post-exercise (45, 58). Hence, each individual bout of

exercise has strong implications for opposing insulin resistance and supports our focus on maximizing the efficacy of each exercise bout.

Whole-body Insulin Sensitivity

Previous research has consistently reported that blacks are more insulin resistant compared to whites, which significantly increases their risk for Type 2 diabetes (38, 40, 41, 48, 52, 61, 71-73, 85). The Insulin Resistance Atherosclerosis Study (IRAS), a large-scale multi-center epidemiological study reported that blacks have significantly higher fasting and two-hour post-prandial insulin concentrations, higher acute insulin responses (AIR), and lower levels of insulin sensitivity compared to their white counterparts (41). After statistically adjusting for age, obesity, body fat distribution, self-reported physical activity and percent calories from fat and fiber, the ethnic/racial disparity was still apparent with lower insulin sensitivity scores in blacks compared to whites. Goran et al (38) and Osei et al (71, 72) replicated these findings in smaller cohorts of black and white children and adults, respectively. Although these studies point towards a biological predisposition for insulin resistance in blacks, none of these researchers have matched their participants for the metabolic risk factors for Type 2 diabetes.

In the present study, we did not observe baseline differences in insulin sensitivity between age, gender BMI-matched whites and blacks; in fact, we observed significantly lower plasma glucose concentrations in blacks compared to their white counterparts. Other studies that have successfully matched the physical characteristics of their black and white subjects have also reported similar findings. Berk *et al*(8) reported similar levels of insulin sensitivity measured by an intravenous glucose tolerance test in healthy, premenopausal, nondiabetic black and white women matched for age, BMI, percent fat

mass, fat free mass, waist-to-hip ratio, visceral adipose tissue and subcutaneous adipose tissue. Winnick *et al* (94) confirmed these findings using the homeostasis modeling assessment (HOMA) in normotensive black and white patients with Type 2 diabetes. These studies together do not support the idea of an inherent predisposition towards insulin resistance in blacks and future research should examine potential environmental determinants of increased insulin resistance reported in this ethnic minority population.

In response to individual bouts of exercise, we observed a greater improvement in insulin sensitivity rather than a reduced response in blacks compared to whites (18% vs. -1.8%, respectively). These findings are consistent with data previously-reported in training studies (11, 94). The HERITAGE study assessed the effect of a 20-week endurance training program in healthy, previously sedentary black and white participants. An intravenous glucose tolerance test was performed before and after a standardized training program in 316 women and 280 men (173 blacks and 423 whites) (11). Mean insulin sensitivity increased by 10% following the intervention, but a larger improvement was reported in blacks (16%) compared to whites (8%), however this difference was not statistically significant. Winnick *et al* assessed ethnic/racial differences in glucose metabolism in response to 8 weeks of resistance or aerobic training in 36 black and 23 white men and women with Type 2 diabetes (94). Blacks responded more favorably to resistance training with a significant improvement in insulin sensitivity. Similar improvements however, were not observed in white patients who underwent an identical volume of exercise. The data from the present study are novel, since they demonstrate that ethnic/racial differences in the insulin sensitivity improvement to exercise are not a result of training but individual bouts of exercise.

The increases in insulin sensitivity reported in blacks after exercise were likely the result of enhanced non-oxidative glucose disposal. Devlin et al has demonstrated in lean and obese individuals that increases in peripheral (muscle) glucose utilization are largely accounted for by increased non-oxidative glucose disposal, which presumably reflect increased glucose storage as glycogen in the postexercise state (28). Hence, the small improvement in non-oxidative glucose disposal reported in white participants may not have been sufficient to elicit a significant improvement in whole-body insulin sensitivity. Because white participants had significantly higher levels of glucose storage during the baseline and exercise conditions compared to their black counterparts, a “ceiling effect” most likely contributed to the lack of improvement in glucose storage in this group. Thus, the major effect of prior exercise was to increase insulin-stimulated glucose disposal in the black participants to alter the pathways of glucose metabolism to favor glucose storage and decrease glucose oxidation.

It is recognized that the impact of exercise on energy metabolism and insulin sensitivity can extend for many hours after exercise, hence studying changes in postexercise substrate oxidation was of interest. Despite similar levels of carbohydrate oxidation during exercise, post-exercise respiratory exchange ratios were significantly higher in blacks compared to whites and total carbohydrate kilocalories expended during the 120-minute recovery period tended to be higher in blacks. Because blacks demonstrated a greater capacity to switch back to carbohydrate use in recovery, it is possible that this group was able to replenish their muscle glycogen stores more rapidly than their white counterparts. Hence, blacks do not require the same degree of augmentation of lipid metabolism and utilization in postexercise recovery. Although

muscle glycogen content was not measured in the present study, future research should directly assess the relationship between post-exercise carbohydrate oxidation, muscle glycogen depletion, and whole-body insulin sensitivity.

Metabolic Flexibility

Metabolic health is associated with an increased capacity to transition between lipid and carbohydrate fuels (56). Termed “metabolic flexibility”, this condition was identified by Kelley and colleagues in lean, healthy individuals compared to obese and Type 2 diabetic individuals (53-56). On the other hand, “metabolic inflexibility” is characterized by excessive carbohydrate oxidation in skeletal muscle during fasting conditions and impaired ability to upregulate carbohydrate oxidation in response to a hyperinsulinemic-euglycemic clamp. Currently, there are conflicting reports of substrate use characteristic of metabolic inflexibility in blacks compared to whites under varied conditions (8, 22, 69, 91). Weyer et al (91) reported significant ethnic/racial differences in 24-hour respiratory quotients in blacks compared to whites. Further analysis revealed that these differences in substrate oxidation were sex specific, with black males oxidizing more carbohydrate at rest compared to white males. In this cohort, ethnic/racial differences were also detected in physical activity energy expenditure, body composition and body fat distribution which could potentially explain the differences in substrate oxidation reported. Chitwood et al (22) did however detect lower rates of fasting fat oxidation in lean, sedentary black women compared to white counterparts and Nicklas et al (69) confirmed these findings in obese, postmenopausal black women. Berk et al (8) examined substrate oxidation in nondiabetic, age/BMI-matched premenopausal black and white women. Ethnic/racial differences were not detected in fasting fat oxidation or

insulin stimulated carbohydrate oxidation during a pancreatic euglycemic clamp. Black participants did however, fail to increase postabsorptive fat oxidation when switched from a low-fat to high-fat eucaloric diet and failed to increase their fat oxidation in response to epinephrine infusions as much as white women did.

To our knowledge, the present study is the first to assess ethnic/racial differences in the metabolic flexibility in substrate use after exercise. Fasting fat oxidation was similar in black and white participants and exercise increased the contribution of fat oxidation at rest in both groups, however these improvements were not statistically significant. Contrary to Berk *et al*'s (8) findings, insulin-stimulated carbohydrate oxidation was significantly higher in blacks compared to whites. Additionally, the difference reported in insulin-stimulated carbohydrate oxidation remained significantly higher in blacks after exercise. It is likely that the insulin infusion rates used by Berk and colleagues (2 and 4 $\text{mU}\cdot\text{m}^{-2}\cdot\text{min}^{-1}$ vs. 40 $\text{mU}\cdot\text{m}^{-2}\cdot\text{min}^{-1}$ in the present study) were insufficient to detect an ethnic/racial difference in insulin-stimulated carbohydrate oxidation. Hence, blacks appear to have a greater capacity to switch from primarily fat oxidation at rest to primarily carbohydrate oxidation during a clamp.

The contribution of dietary energy balance, macronutrient composition, and/or other nutritional factors to metabolic flexibility and post-exercise substrate oxidation were not addressed in the present study. Previous research does not support the hypothesis that blacks consume more food compared to their white counterparts (49). To minimize the confounding impact of those factors on the outcomes of interest in the current study, all food was provided for participants using standardized meals in the 12

hours prior to each measurement. Nevertheless, it is possible that composition of habitual diet could partially explain some of the results reported in the present study.

Summary

By design, risk factors for diabetes (age, BMI, fat mass, habitual physical activity) were minimized to isolate ethnic/racial differences in the metabolic responses to exercise, hence the results presented in this study may not be generalizable to at-risk black populations. Future research should examine ethnic/racial differences the insulin sensitivity response to exercise in an insulin-resistant, prediabetic population to obtain a better understanding of the influence of insulin resistance on the metabolic response to individual bouts of exercise in both blacks and whites. Additionally, future research should examine the underlying mechanisms of increased insulin resistance previously-reported in black populations.

In conclusion, this study provides strong evidence in support of using exercise to enhance glucose metabolism and reduce risk of Type 2 diabetes in young, previously-sedentary but otherwise healthy blacks. We have demonstrated that blacks' achieve greater improvements in the insulin sensitivity response to exercise compared to their white counterparts which can be attributed to increased non-oxidative glucose disposal and possibly enhanced post-exercise glucose oxidation. Additionally, blacks demonstrate greater metabolic flexibility in substrate use compared to whites however individual bouts of exercise enhanced fasting fat oxidation to an equal degree in both groups. If these results are confirmed in a larger cohort, ethnic/racial differences in the metabolic responses to exercise could potentially have strong public health implications for blacks. If blacks decrease their risk for diabetes with one bout of exercise, emphasizing the

metabolic benefits accumulated during individual bouts of exercise could potentially increase the adoption of exercise to reduce insulin resistance in this ethnic/minority population.

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Table 3. Subject Characteristics. Mean \pm SD.

Ethnicity/Race	Black	White	p-value
Gender	7F/4M	6F/4M	---
Age (years)	26.0 \pm 7.2	22.4 \pm 7.1	0.45
Height (in)	66.4 \pm 3.4	66.8 \pm 3.7	0.99
Weight (kg)	81.6 \pm 9.5	81.4 \pm 22.2	0.97
Body Mass Index (kg/m ²)	28.9 \pm 4.4	28.0 \pm 6.3	0.69
Body Composition (% fat)	34.5 \pm 12.7	35.5 \pm 8.4	0.84
Truncal Fat (%)	45.5 \pm 3.6	47.1 \pm 3.4	0.35
Muscle Mass (kg)	49.4 \pm 10.1	47.9 \pm 10.5	0.77
Resting Metabolic Rate (kcal/day)	1602.1 \pm 354.0	1625.7 \pm 427.2	0.89
Physical Activity Score	1.5 \pm 0.8	1.8 \pm 0.6	0.30

Figure 8. Glucose and Insulin Concentrations during the Baseline and Exercise Clamps. Mean \pm SD.

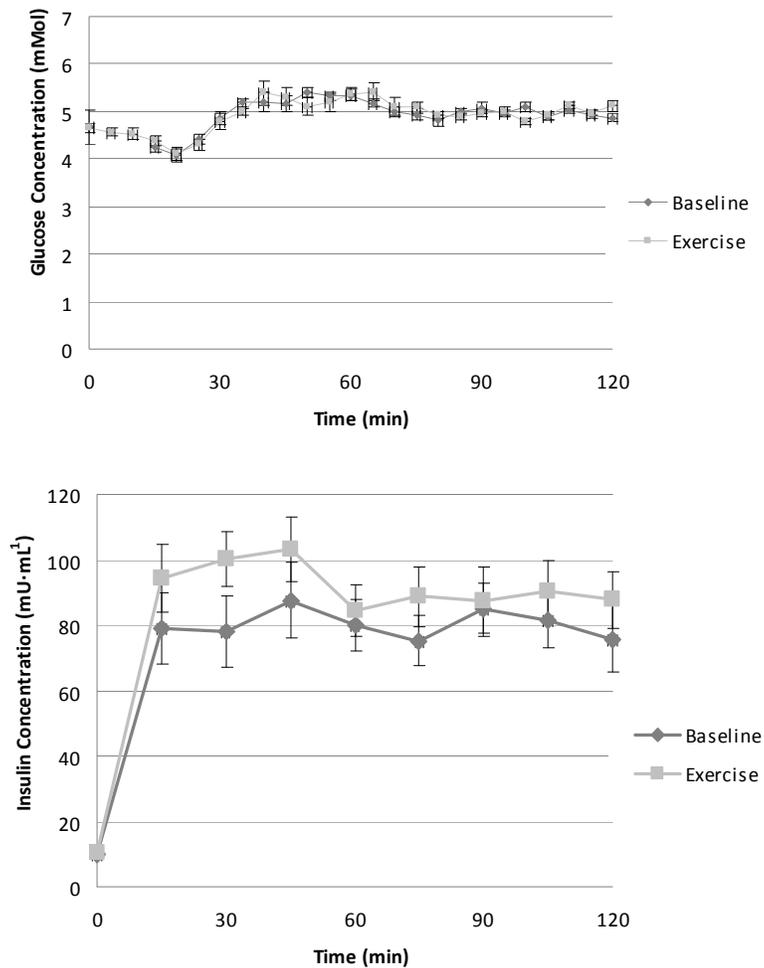


Table 4. Fasting Free Fatty Acid, Glucose Insulin and Triglyceride Concentrations. Mean \pm SD. *Significant effect of exercise at $p < 0.05$. # Significant effect of race at $p < 0.05$.

	Black		White		p-value
	Baseline	Exercise	Baseline	Exercise	
Free Fatty Acids (mEq· L ⁻¹)*	0.48 \pm 0.05	0.64 \pm 0.03	0.51 \pm 0.05	0.67 \pm 0.05	0.7
Glucose (mg· dL ⁻¹) #	82.3 \pm 2.4	80.0 \pm 3.7	87.1 \pm 5.9	88.8 \pm 5.0	0.01
Insulin (uU j mL)	85.0 \pm 7.0	83.6 \pm 11.0	93.9 \pm 8.8	99.6 \pm 10.0	0.83
Triglycerides (mg·dL ⁻¹)	78.0 \pm 69.4	74.1 \pm 49.7	110.9 \pm 88.4	88.4 \pm 32.45	0.29

Figure 9. Whole-body Insulin Sensitivity during the Hyperinsulinemic-euglycemic Clamp. *Significant effect of race at $p < 0.05$.

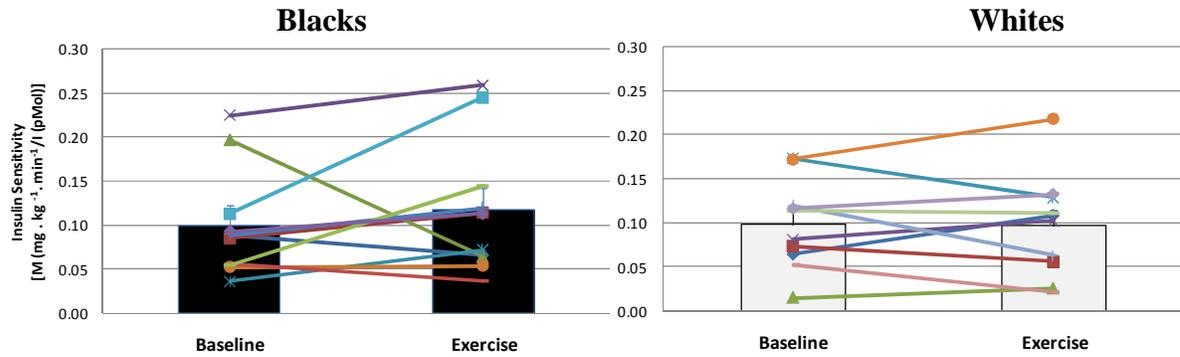


Figure 10. Oxidative and Non-Oxidative Glucose Disposal during the Hyperinsulinemic-euglycemic Clamp. *Significant effect of race at $p < 0.05$.

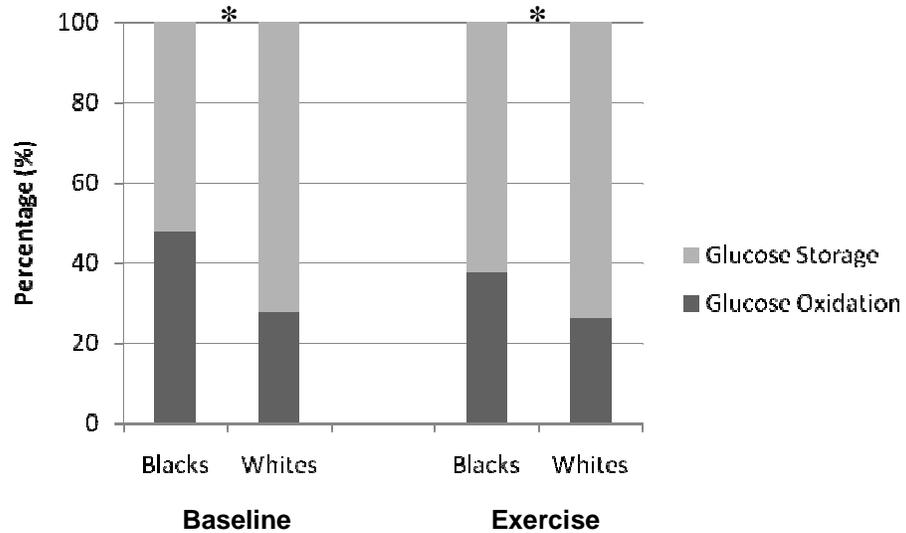


Figure 11. Metabolic Flexibility during the Hyperinsulinemic-euglycemic Clamp.
*Significant effect of race at $p < 0.05$.

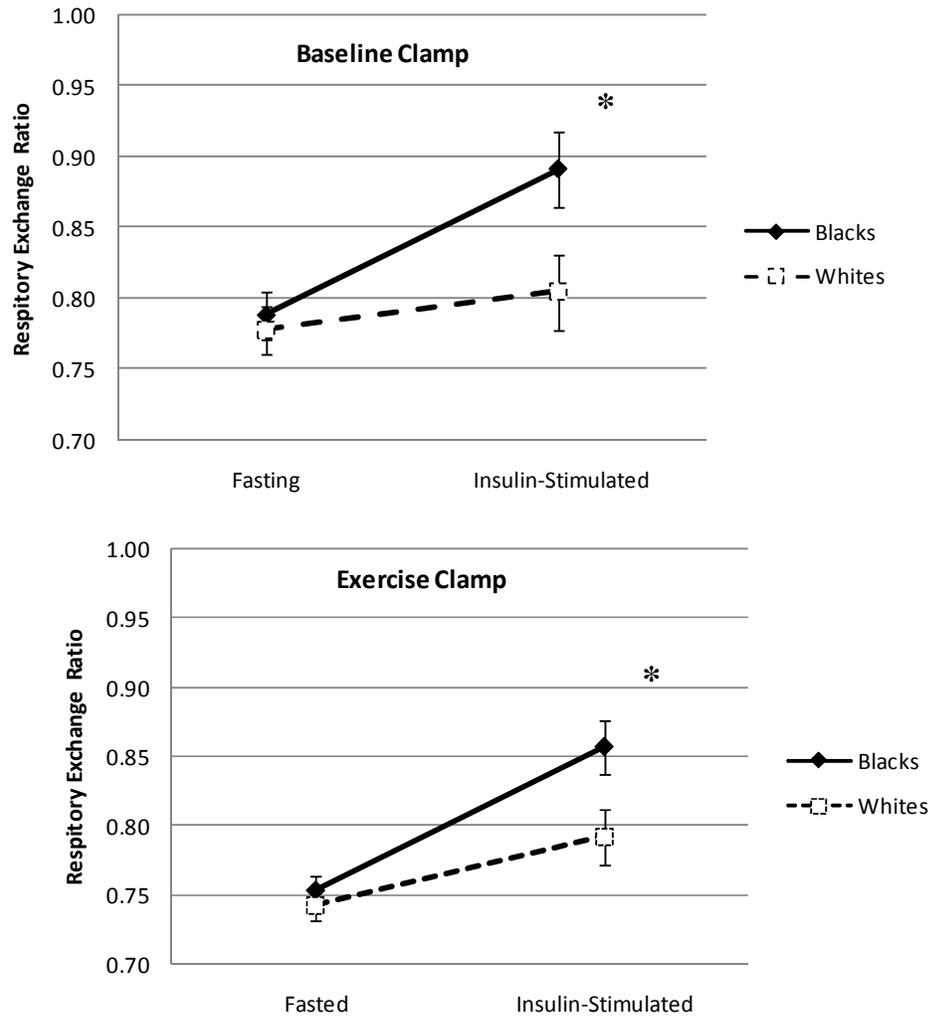


Figure 12. Substrate Oxidation during Blood Measurements, Exercise, and Post-Exercise.
 *Significant effect of race at $p < 0.05$.

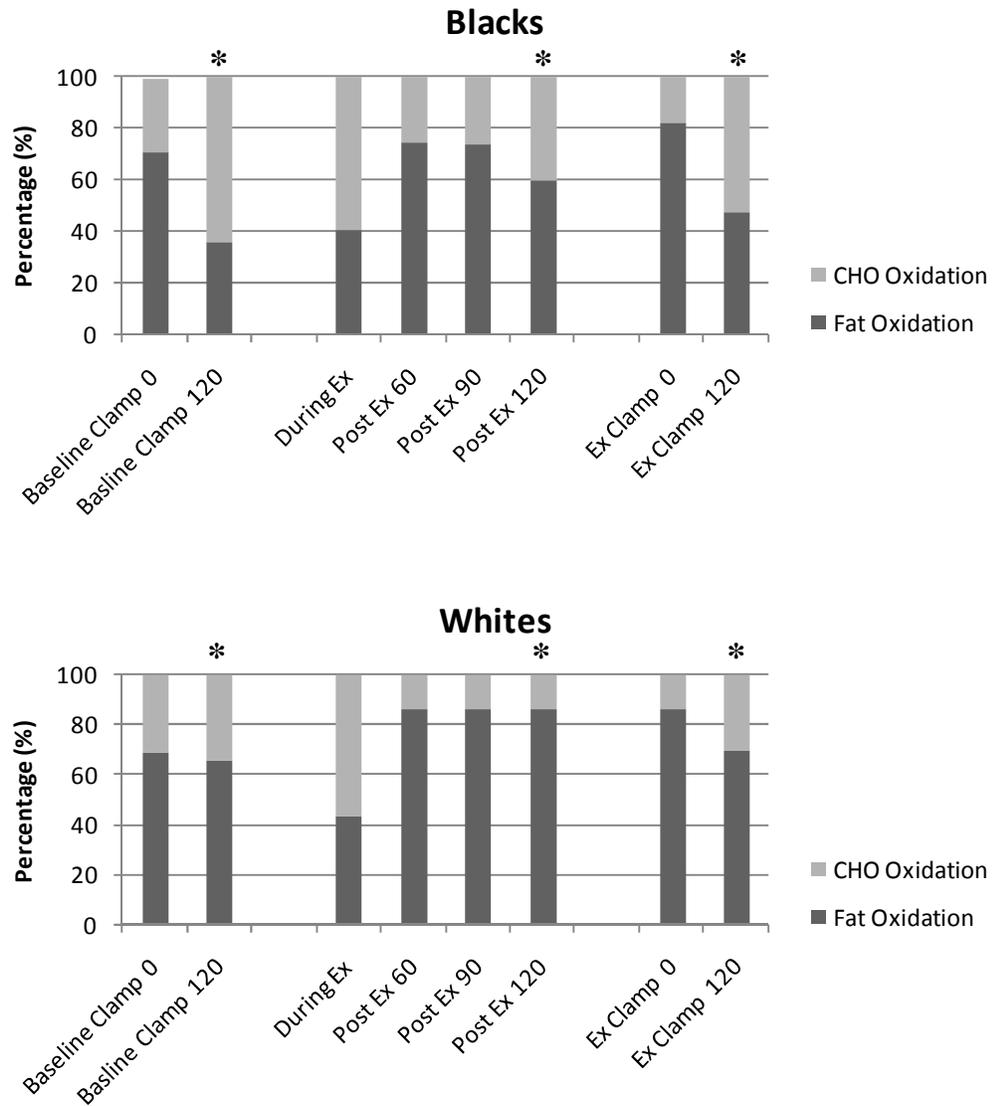
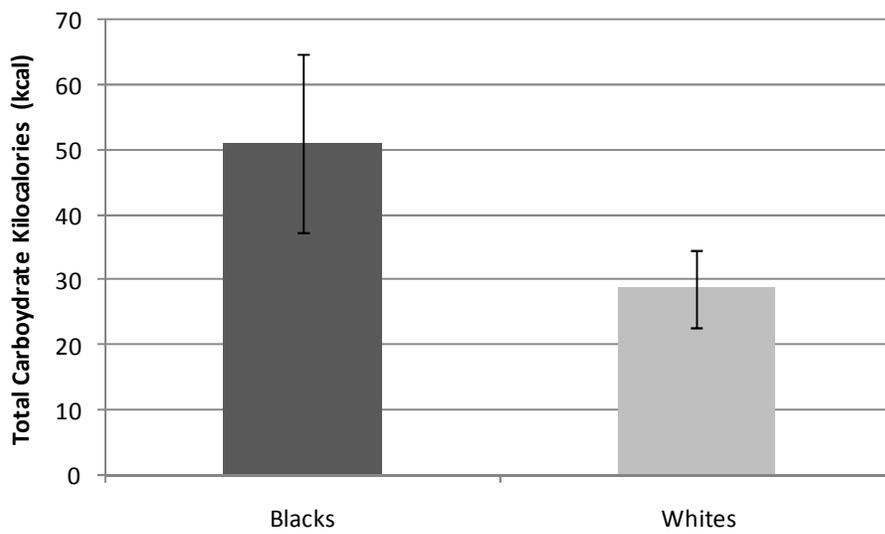
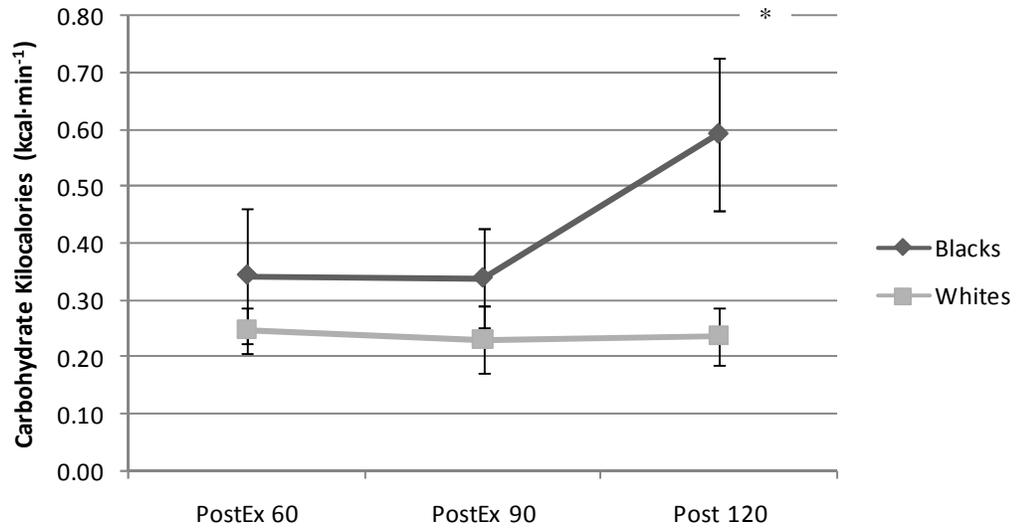


Figure 13. Post-exercise carbohydrate kilocalories expended in blacks and whites. Mean \pm SD. *Significant effect of race at $p < 0.05$.



CHAPTER V

**PSYCHOSOCIAL RESPONSES TO ACUTE EXERCISE IN SEDENTARY
BLACK AND WHITE INDIVIDUALS**

**Rebecca Hasson¹
Kirsten Granados¹
David X. Marquez²
Gary Bennett³
Patty Freedson¹
Barry Braun¹**

¹University of Massachusetts, Amherst Department of Kinesiology

²University of Illinois, Chicago, Department of Kinesiology and Nutrition

³Duke University Medical Center

Corresponding author: Barry Braun

**University of Massachusetts
Department of Kinesiology
Totman Building
Amherst, MA 01003**

Phone: (413) 545-1337

FAX: (413) 545-2906

Email: bbraun@kin.umass.edu

Running Title:

Abstract

INTRODUCTION: Non-Hispanic blacks (blacks) are less physically active compared to non-Hispanic whites (whites). Previous research has suggested blacks start exercise programs; however, adherence is higher in whites. Ethnic/racial differences in psychosocial responses to exercise such as mood, state-anxiety and exercise task self-efficacy may explain why blacks are more likely to withdraw from exercise programs.

PURPOSE: The objective of this study is to compare psychosocial determinants of exercise and outcomes for individual exercise bouts in blacks and whites. **METHODS:** To assess changes in psychosocial outcomes for exercise, questionnaires assessing mood, state anxiety, and exercise task self-efficacy were administered before and after a bout of exercise to previously sedentary black (n=16) and white (n=15) participants. To assess mood during exercise, in-task mood and rating of perceived exertion were measured every five minutes. On three separate occasions, participants walked on a treadmill at $75\%_{\max HR}$ for 75 minutes at the same time of day and same day of the week (excluding weekends) for three consecutive weeks. Confounding variables that could impact the response to exercise (e.g. environment, time of day, day of week, and visual/auditory stimuli) were controlled. **RESULTS:** Whites reported significantly higher pre and post-exercise levels of distress and fatigue ($p < 0.05$). Both blacks and whites demonstrated significant improvements in exercise self-efficacy (exercise bout 1, $p = 0.003$; exercise bout 2, $p = 0.006$) and psychological distress (all three bouts, $p = 0.006$). During exercise, black participants reported significantly higher in-task mood scores (all three bouts, $p = 0.003$) and a significantly lower rate of perceived exertion (exercise bout 3, $p = 0.04$) compared to white participants, however similar heart rates were recorded in both groups. There were no ethnic/racial differences reported in pre-post measures of state-anxiety, well-being, and fatigue. **CONCLUSION:** These data suggest there may be ethnic/racial differences in in-task mood during exercise and rate of perceived exertion; however these differences in psychosocial outcomes during exercise do not help to explain the low adherence to exercise programs reported in blacks.

Introduction

Despite the benefits of physical activity, more than half of adults in the United States are not regularly active at the recommended levels with ethnic/racial minority populations reporting the highest prevalence of leisure-time physical inactivity (21). Specifically, physical inactivity is significantly higher in non-Hispanic blacks (blacks; men= 27.0%, women = 33.9%) compared to non-Hispanic whites (whites; men = 18.4%, women = 21.6%) (21). The ethnic/racial disparity in physical inactivity does not appear to be the result of apathy towards exercising in blacks, but to more attrition from exercise programs. Blacks reportedly start exercise programs at comparable rates to whites (17) but adherence to these programs is significantly lower in blacks (93).

Social Cognitive Theory (6) has been used extensively to explain and influence exercise behavior, however psychosocial determinants for exercise which include self-regulatory exercise self-efficacy, social support for exercise, outcome expectations and perceived barriers do not fully explain the ethnic/racial disparity in physical activity participation. Despite their decreased engagement in leisure-time physical activity, blacks tend to: overestimate their level of self-regulatory exercise self-efficacy (3, 35, 89, 92, 93); report higher levels of social support for exercise (33, 35); and cite similar outcome expectations for exercise compared to whites (17). Nevertheless, improvements in self-efficacy and social support for exercise increase exercise behavior in both races (6, 7). Because these determinants do not appear to be driving the ethnic/racial disparity in physical activity participation, it is necessary to understand psychosocial outcomes of exercise, which could in part explain why blacks and whites have similar rates of adoption but different rates of adherence to exercise programs.

The psychological benefits of regular physical activity are well-documented (19, 88). Multiple reviews and meta-analyses have convincingly reported that exercise has a beneficial effect on depression (70, 84), anxiety (60, 84), and cognitive functioning (e.g., executive control processes) (68). Furthermore, acute bouts of exercise are associated with improved mood (5, 25, 26), decreased state-anxiety (60), and improved exercise task self-efficacy (57). Only recently has there been any systematic investigation into the responses *during* exercise (36). This time frame is potentially very important for understanding the changes in mood responses throughout an exercise session. It is possible that mood experienced during an exercise bout (or in-task mood) can be quite different from the mood change reported before and after exercise. Additionally, post-exercise positive mood might not be sufficient to “override” the negative in-task mood experienced during exercise.

Although the data are derived from only one study, “feeling better” was cited as the number one reason blacks reported engaging in regular physical activity (17). A less positive response to each exercise bout may explain why blacks are more likely to discontinue exercise programs. To our knowledge no study has directly examined potential ethnic/racial differences in psychosocial outcomes before, during, and after individual exercise bouts in blacks and whites. Therefore, the purpose of this study was to compare the psychosocial responses to single bouts of exercise in 15 blacks and 15 age/gender/BMI-matched whites.

Methods

Environmental Conditions. To minimize differences in environmental determinants of physical activity (e.g., education level, neighborhood safety, lack of

transportation, lack of access to gyms), thirty-one previously sedentary but otherwise healthy men and women from the university community were recruited to participate in this study.

Subjects. All participants belonged to one of two ethnic/racial groups: non-Hispanic black or non-Hispanic white. Ethnicity/race was defined as persons having resided in the United States for the past 5 years who self-identify themselves as belonging to either the black or white race. All participants were free from cardiovascular, respiratory, metabolic and mental health disorders (e.g., hypertension, asthma, coronary heart disease, Type 2 diabetes, or depression). All subjects read and signed an informed consent document approved by the University Institutional Review Board.

Baseline Measurements. Before the first exercise session, psychosocial questionnaires were administered to describe and characterize the study participants. Social Cognitive Theory (6), developed from the Social Learning Theory, was employed to assess determinants and outcomes of exercise. As previously stated, Social Cognitive Theory is a theoretical framework extensively used in the study of physical activity behavior. It offers a comprehensive framework for understanding and describing health behaviors and changing them. Self-efficacy is the main construct of Social Cognitive Theory and other determinants include outcome expectations and personal/environmental barriers. Participants answered questionnaires that assessed their perceptions of physical activity and participation in exercise. Specifically, these questionnaires were designed to assess self-regulatory exercise self-efficacy (Exercise Self-efficacy Scale), social support to exercise (Social Support and Exercise Scale), outcome expectations for exercise

(Outcome Expectations for Exercise Scale) and perceived barriers to exercise (Exercise Barriers Questionnaire).

Exercise Protocol. All participants came to the Energy Metabolism Laboratory to complete one exercise session per week for three consecutive weeks. Participants walked on a treadmill at 75% of maximal heart rate for 75 minutes (4 periods of 15 minutes at the predetermined speed interspersed with 5-minutes at a slow speed of 2.0 mph). Each exercise session included a 5-minute warm-up and cool-down period. Breath samples were taken during one 15-minute bout and a heart rate monitor was worn continuously to objectively verify exercise intensity. Psychosocial responses to exercise can be influenced by the context in which the exercise takes place (6). To minimize environmental influences on the data obtained, day of the week (weekends excluded), time of day, visual and auditory stimuli (television viewing during exercise) were standardized. Additionally, participants were not provided with any feedback regarding their physiological state (kilocalories burned, heart rate response during exercise) until after they had completed the study.

Outcome Measures. To assess pre-post changes in psychosocial outcomes for exercise, questionnaires assessing mood (Subjective Exercise Experiences Scale), exercise task self-efficacy (Self-Efficacy Scale for Duration), and state anxiety (State Trait Anxiety Inventory) were administered before and after each bout of exercise. To assess mood during exercise, participants answered questions regarding “how do you feel” and “how hard do you feel you are exercising”. Feeling Scale (FS) and Borg’s Rating of Perceived Exertion (RPE) were used as a measure of in-task mood and

perceived exercise intensity, respectively. These measures were taken every five minutes during exercise and a schedule of measurements is presented below (**Table 5**).

Measures.

Psychosocial Determinant for Exercise. The **Exercise Self-Efficacy Scale** (64) assessed the individual's beliefs in their ability to exercise on a four-time per week basis at moderate intensities for 30 minutes or more per session for six months. Summing the efficacy scores and dividing by the total number of items in the scale calculated an average efficacy score:

$$[(\text{score } 1 + \text{score } 2 + \text{score } 3 + \text{score } 4 + \text{score } 5 + \text{score } 6) \div 6] ,$$

resulting in a maximum possible efficacy score of 100. Support has been established for the internal consistence of the Exercise Self-Efficacy Scale (alpha coefficient of .95) and its validity in ethnically-diverse populations (62, 66, 67, 93).

The **Social Support and Exercise Scale (SSES)** (82) measured social support specifically related to exercise habits. The 13-item scale assessed social support from friends and family, respectively, during the last three months. SSES scores were broken down into Family Participation, Family Rewards and Punishment, and Friend Participation subscales. Participants were asked to rate (1 = never, 2 = rarely, 3 = a few times, 4 = often, and 5 = very often) how often their family, and friends encouraged their participation and involvement in exercise. Hence, each participant received a separate social support for exercise score for family and friends and when combined yields a total support score (possible score range of 13 to 65). The SSES has demonstrated adequate validity and reliability (13, 78).

The **Outcome Expectations for Exercise (OEE) Scale** (79) was developed based on Bandura's theory of self-efficacy and contains nine items assessing the extent to which one believes that engaging in exercise will result in specific outcomes. Responses were made on a 5-point Likert scale (1 = strongly agree to 5 = strongly disagree). The responses to all nine items were then summed with a possible range of 9-45, in which lower scores are related to greater outcome expectations. Support has been established for the internal consistency of the OEE scale (alpha coefficient of .89) and for its validity; i.e. those who exercised regularly had greater OEE than those who did not.

The **Exercise Barriers questionnaire** (57) consists of ten often-reported personal barriers to exercise and physical activity, including lack of time and feeling too tired to exercise. The frequency with which each barrier occurred was rated on a 5-point scale (1 = never to 5 = very often). Several items were added to the scale, which represent common exercise barriers reported by ethnic/racial minorities in the United States (e.g., lack of transportation and lack of facilities).

Psychosocial Outcomes of Exercise. The **Exercise Self-Efficacy Scale for Duration** assessed individual's beliefs in their ability to walk at a moderate intensity without stopping. The scale consisted of six items, with each item representing one 10-minute increment. For each item on the scale, participants were asked to indicate how confident they were that they could successfully carry out the specific activity. The responses were scored on a 100-point percentage scale (100% = complete confidence, 0% = no confidence at all). Summing the efficacy scores and dividing by the total number of items in the scale calculated an average efficacy score:

$$[(\text{score } 1 + \text{score } 2 + \text{score } 3 + \text{score } 4 + \text{score } 5 + \text{score } 6) \div 6] ,$$

resulting in a maximum possible efficacy score of 100. This scale has been shown to be valid and reliable in the general population, including ethnic/racial minorities (51, 62).

The **State Trait Anxiety Inventory (STAI)** (86) is the definitive instrument for measuring anxiety in adults. The STAI has twenty questions with four possible responses to each. The items were summed to produce a total score in which higher scores equate to greater state anxiety. The STAI has been shown to be valid and reliable (90).

To evaluate pre- and post- exercise changes in mood, participants were asked to complete the **Subjective Exercise Experiences Scale (SEES)** (65). The SEES is a 12-item, three-dimensional scale that assessed three general categories of in-task mood responses to exercise: positive well-being (e.g., great), psychological distress (e.g. miserable), and fatigue (e.g., tired). For each item participants were asked to indicate how strongly they were experiencing the feeling state at that time. Items were scored on a 7-point Likert scale, with scores from each subscale ranging from “not at all” (1) and “very much so” (7). Each sub-scale ranges from 4 to 28 with higher scores representing greater fatigue, positive well-being or distress. The SEES has been shown to have a high internal consistency across a variety of populations (65).

To evaluate in-task mood responses during acute bouts of exercise, the **Feeling Scale** (27, 80) was employed. Every five minutes during the exercise participants were asked, “How do you feel right now?” Participants responded by selecting from an eleven-point scale, ranging from -5 (‘I felt very bad’) through neutral to +5 (‘I felt very good’).

To determine perceived exercise intensity during exercise, **Rating of Perceived Exertion (RPE)** (10) was utilized. Participants were asked “How hard do you feel you are working?” Participants responded by selecting from a fifteen-point scale ranging from

6 ('no exertion at all') to 20 ('maximal exertion'). The time course of changes in in-task mood, RPE and heart rate measures were examined across each bout of exercise.

Statistical Analysis. Ethnic/racial differences in baseline measurements (age, BMI, exercise self-regulatory self-efficacy, social support for exercise, outcome expectations, perceived barriers, exercise task self-efficacy, state anxiety, and mood) were assessed with standard summary statistics and compared using two-sample t-test. It was hypothesized that the positive psychosocial effects on exercise task self-efficacy, state-anxiety, and mood after each bout of exercise would be smaller in blacks compared to whites. Therefore, a three-factor repeated measures ANOVA was implemented to assess post-exercise changes in psychosocial outcomes (main effects: race by treatment by time; interactions: ethnicity x treatment and ethnicity x time). Tukey's post-hoc analyses were completed to determine which time points were statistically different. Differences between ethnic/racial groups, conditions, and time were considered statistically significant at $\alpha < 0.05$.

Results

Baseline Characteristics. Sixteen Non-Hispanic blacks and 15 non-Hispanic whites of similar age, BMI, and physical activity status completed the study protocol. No significant differences were detected between the two groups for any of the baseline physical measures (**Table 6**). All participants were able to complete 75 minutes of brisk walking on the treadmill, during which they expended approximately 480 kilocalories. The average heart rate during exercise was 137 ± 2.5 beats per minute in black participants and 132 ± 3.1 beats per minute in white participants ($p = 0.20$). In terms of psychosocial determinants for exercise, blacks reported significantly higher outcome

expectations for exercise ($p = 0.03$) however, social support for exercise and self-regulatory exercise self-efficacy were similar in both groups. Whites tended to report more barriers to exercise ($p = 0.06$) (**Table 7**). The top three barriers in both black and white participants were “lack of time”, “feeling too tired to exercise” and “self-conscious about physical appearance”.

Psychosocial Outcomes for Exercise. As previously stated, the SEES is a 12-item, three-dimensional scale that assesses three general categories of mood responses to exercise: positive well-being (e.g., great), psychological distress (e.g. miserable), and fatigue (e.g., tired). For all exercise bouts, whites reported significantly higher pre and post-exercise levels of psychological distress compared to black participants ($p = 0.006$). However, exercise significantly decreased psychological distress to a similar degree in both groups ($p = 0.0006$) (**Figure 14**). Pre-exercise levels of fatigue were significantly higher in whites compared to black participants (exercise bout 1 only; $p = 0.02$) but there was no effect of exercise on fatigue scores in either group ($p = 0.83$). There were no ethnic/racial differences in exercise self-efficacy for duration ($p = 0.25$) however exercise significantly improved self-efficacy scores in both groups (exercise bout 1 and 2 only, $p = 0.02$) (**Figure 15**). There were no ethnic/racial differences reported in pre- and post-measures of state-anxiety ($p = 0.20$) and positive well-being ($p = 0.08$).

In-task mood, RPE and HR during Exercise. Both groups reported lower in-task mood scores ($p < 0.0001$), higher RPE ($p < 0.0001$) and higher HR ($p < 0.0001$) during exercise, compared to the beginning and end of exercise. Black participants reported significantly higher in-task mood scores (all three bouts, $p = 0.003$) compared to white participants (**Figure 16**). Despite similar heart rates between groups ($p = 0.20$)

(**Figure 17**), black participants recorded a significantly lower rating of perceived exertion (exercise bout 3 only, $p = 0.01$) compared to white participants (**Figure 18**).

Discussion

The primary aim of this study was to compare psychosocial outcomes to individual exercise bouts in blacks and age/gender/BMI-matched whites. The major findings of this study were that individual bouts of exercise improved exercise task self-efficacy and reduced psychological distress in both black and white participants; however there were no ethnic/racial differences in these psychosocial responses to individual bouts of exercise. Ethnic/racial differences were apparent *during* exercise with black participants reporting higher positive in-task mood during all three bouts of exercise and lower RPE scores during the third bout, despite similar heart rates in both groups.

It is recognized that a single bout of exercise does not reflect the adaptations seen with chronic (weeks/months) exercise training. A body of research has documented that the majority of the improvements in exercise task self-efficacy, state-anxiety, and mood are transient effects of recent exercise (25, 26, 57, 77). Hence, each individual bout of exercise is important and supports our focus on optimizing the psychosocial effects garnered after each exercise bout. Enhancing the improvements associated with individual bouts of exercise may maximize the efficacy of each exercise bout and the probability that an individual will engage in a subsequent exercise bout.

In the present study, psychosocial determinants of exercise were similar in both blacks and whites, with the exception of outcome expectations for exercise. As previously noted, both black and white participants reported similar levels of self-regulatory exercise self-efficacy. There was a trend for whites to report higher barriers to

exercise but this finding was not statistically significant. Previous research has reported ethnic/racial differences in self-regulatory exercise self-efficacy with blacks overestimating their level of self-efficacy (3, 35, 89, 92, 93) but this did not appear to be an issue in our subject population. In addition, black and white participants reported similarly low levels of social support for exercise from friends and even lower levels of social support from family, which could, in part, contribute to their sedentary lifestyles. On the other hand, both groups reported high outcome expectations for exercise with black participants reporting significantly higher levels of outcome expectations for exercise compared to whites. The high level of education reported in the subject population most likely influences this finding; nevertheless high outcome expectations for exercise did not translate into an active lifestyle in either group.

Pre- and post-exercise measures of exercise-task self-efficacy did not differ by ethnicity/ race. Both black and white participants reported moderate-to-high baseline levels of exercise task self-efficacy (65.3 ± 25.2 vs. 73.7 ± 22.2 , respectively) and improvements in self-efficacy after the first two bouts of exercise were similar in both groups. A “ceiling effect” most likely contributed to the lack of improvement reported in the third bout of exercise. During bout 3, black and white participants reported high baseline levels of exercise task self-efficacy (83.9 ± 8.0 vs. 87.5 ± 15.8 , respectively). It is probable that participants maximized their potential to improve their exercise task self-efficacy by successfully completing two previous bouts of exercise at the same intensity and duration. Bandura (6) explains that each exercise bout serves as a mastery experience to enhance exercise-task self-efficacy. Therefore, emphasizing improvements in exercise task self-efficacy may potentially lead to the adoption and adherence to exercise

programs in both black and white populations (6). The overall improvements in exercise task self-efficacy were similar to previous research demonstrating the beneficial effect of single bouts of exercise on self-efficacy regardless of race (93).

Exercise did not reduce state-anxiety in either the black or white participants. This finding may be explained in part by the intensity and duration of exercise prescribed in the present study. Petruzzello *et al* (77) observed significant reductions in state-anxiety in participants who completed 15-minute and 30-minute bouts of treadmill running at 75% VO_{2max} . It is difficult to make direct comparisons with this study because of differences in intensity, duration, mode of exercise used, as well as differing levels of fitness, but it is likely that these factors played a key role in reducing state-anxiety after individual bouts of exercise. To ensure that our previously-sedentary population could successfully complete each exercise session, we prescribed an exercise intensity and duration corresponding to current Institute of Medicine guidelines (~60% VO_{2max} for 60 minutes) (1). It is possible a shorter duration or higher intensity of exercise may have been necessary to demonstrate improvements in state anxiety.

Before exercising, white participants reported higher levels of psychological distress and fatigue and similar levels of positive well-being compared to black participants. Although it is unclear why these pre-exercise differences existed in our cohort it is important to note that distress and fatigue scores were extremely low in both groups. Future research should verify these results before attributing this discrepancy to an ethnic/racial difference. Nevertheless, pre-exercise scores did not influence the exercise response to mood. Both black and white participants reported decreased levels of psychological distress but no improvements in well-being or fatigue after exercise.

Previous research investigating changes in mood after individual bouts of exercise have observed similar findings in psychological distress but differing results in positive well-being (27, 80). Rudolph *et al* (80) investigated the effect of 10, 15, and 20-minute bouts of treadmill running on mood scores at moderate intensity. All participants reported increased positive well-being and decreased psychological distress at all three durations from baseline to 20 minutes after exercise. Daley *et al* (27) compared the effect of 15 minutes of exercise with a 30-minute bout of exercise on individuals' mood scores both during and after exercise. Positive mood responses were reported after both the 15 and 30-minute exercise bout and these effects were still evident two hours post-exercise. The exercise dose prescribed in the present study was sufficient to elicit improvements in psychological distress but the longer duration of exercise may have blunted the improvements in positive well-being and fatigue previously reported at 15- and 30-minutes of exercise.

During exercise, both black and white participants reported positive in-task mood scores at the start (minute 1), during, and at the end of exercise (minute 75), however in-task mood declined significantly throughout the exercise session. Focht *et al* reported similar responses to an acute bout of aerobic exercise in sedentary older and younger adults. Both age groups reported reduced pleasant feeling states and lower task self-efficacy after completing a 20-min bout of stationary cycling at 65% of VO_{2max} (36). Although in-task mood decreased in both groups in the present study, mood scores were never negative and positive in-task mood was higher in blacks during all three bouts of exercise. Additionally, RPE decreased progressively with each bout of exercise in blacks compared to whites, despite slightly higher heart rates in black participants. These

findings suggest that each bout of exercise became progressively easier for black participants and they felt better during exercise as well. Previous research has revealed that changes in self-efficacy during exercise are related to feelings of fatigue during, which can potentially influence in-task mood (36). It is possible that task self-efficacy improved during exercise as well as after exercise in blacks, which could have contributed to the enhanced mood during exercise, experienced in this group. Conversely, in whites self-efficacy may have decreased during exercise leading to decreased positive in-task mood. Future research should examine self-efficacy during exercise to explain differences in positive in-task mood and RPE reported in the present study between blacks and whites.

By design, environmental determinants of exercise (level of education, neighborhood safety, lack of transportation, lack of access to facilities) were minimized to isolate psychosocial responses to exercise in the personal domain. As compared with previous research, our findings provide greater insight into the independent effects of individual bouts of exercise on state-anxiety, mood and task self-efficacy. Future research should examine other personal and environmental constructs of Social Cognitive Theory (e.g., exercise enjoyment, perceived health status, perceived neighborhood safety, caregiving duties, etc.) to obtain a better understanding of its influence on exercise behavior in both black and white populations.

In conclusion, ethnic/racial differences in the psychosocial response to individual exercise bouts do not appear to be related to the lower adherence rates to exercise programs reported in blacks compared to whites; in fact our results suggests the opposite. If these results are confirmed in a larger, free-living population, improvements in

psychosocial outcomes for exercise could potentially have strong public health implications for blacks. If “feeling better” is an important determinant for exercise behavior in blacks, emphasizing the psychological benefits during individual bouts of exercise could potentially increase adoption and adherence rates to exercise programs in this ethnic/minority population.

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Table 5. Time Table for Psychosocial Measurements.

Measurement	Exercise Bout 1-3		
	Pre-	During	Post-
Task Self-Efficacy	x		x
State Anxiety	x		x
Mood	x		x
In-Task Mood		x	
Rating of Perceived Exertion		x	
Heart Rate		x	

Table 6. Subject Characteristics. Mean \pm SD.

Ethnicity/Race	Black	White	p-value
Gender	11F/5M	10F/5M	---
Age (years)	26.0 \pm 7.2	22.3 \pm 6.9	0.42
Height (in)	66.4 \pm 3.4	66.9 \pm 3.5	0.99
Weight (kg)	81.6 \pm 9.5	77.3 \pm 19.0	0.50
Body Mass Index (kg/m ²)	28.9 \pm 4.4	26.6 \pm 5.5	0.45
Exercise Energy Expenditure (kcal)	501.7 \pm 107.8	463.3 \pm 136.4	0.37
Exercise Oxygen Consumption (l/min)	1.7 \pm 0.4	1.6 \pm 0.5	0.92
Exercise Oxygen Consumption (ml/kg/min)	20.6 \pm 2.9	19.0 \pm 4.8	0.84
Heart Rate (bpm)	137 \pm 2.5	132 \pm 3.1	0.20
Physical Activity Score	1.5 \pm 0.8	1.8 \pm 0.6	0.30

Table 6. Psychosocial Determinants.

Ethnicity/Race	Mean \pm SD		p-value
	Non-Hispanic Black	Non-Hispanic White	
Outcome Expectations*	16.4 \pm 4.5	19.9 \pm 4.2	0.03
Barriers	23.2 \pm 5.4	27.0 \pm 5.5	0.06
Highest Barrier	lack of time	lack of time	-----
Social Support (family)	17.3 \pm 8.0	18.0 \pm 6.0	0.79
Social Support (family_rewards/punishment)	4.4 \pm 4.2	5.8 \pm 6.2	0.47
Social Support (friends)	24.4 \pm 11.4	24.1 \pm 8.1	0.93
Exercise Self-Efficacy	57.5 \pm 27.6	52.2 \pm 21.3	0.56

* Significance at p <0.05

Figure 14. Average Change in Mood (psychological distress) Scores. Mean \pm SE.
 *Significant effect of exercise at $p < 0.05$.

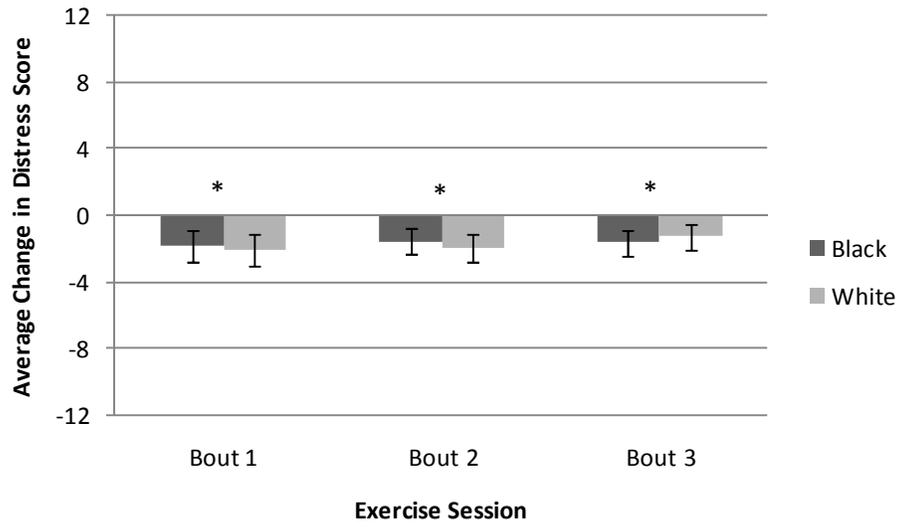


Figure 15. Average Change in Exercise Task Self-Efficacy for Duration Scores. Mean \pm SE. *Significant effect of exercise at $p < 0.05$.

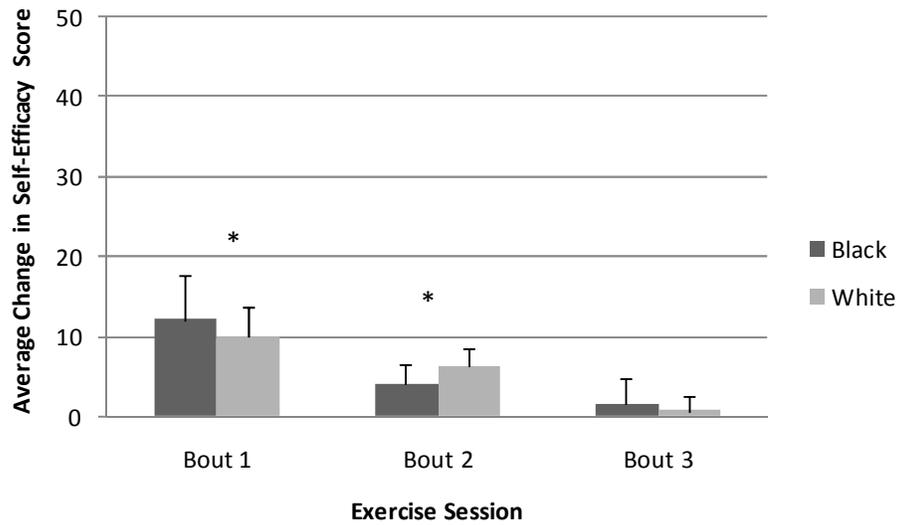


Figure 16. In-task Mood Score during Exercise for Each Exercise Bout. Mean \pm SE.
 *Significant effect of exercise at $p < 0.05$.

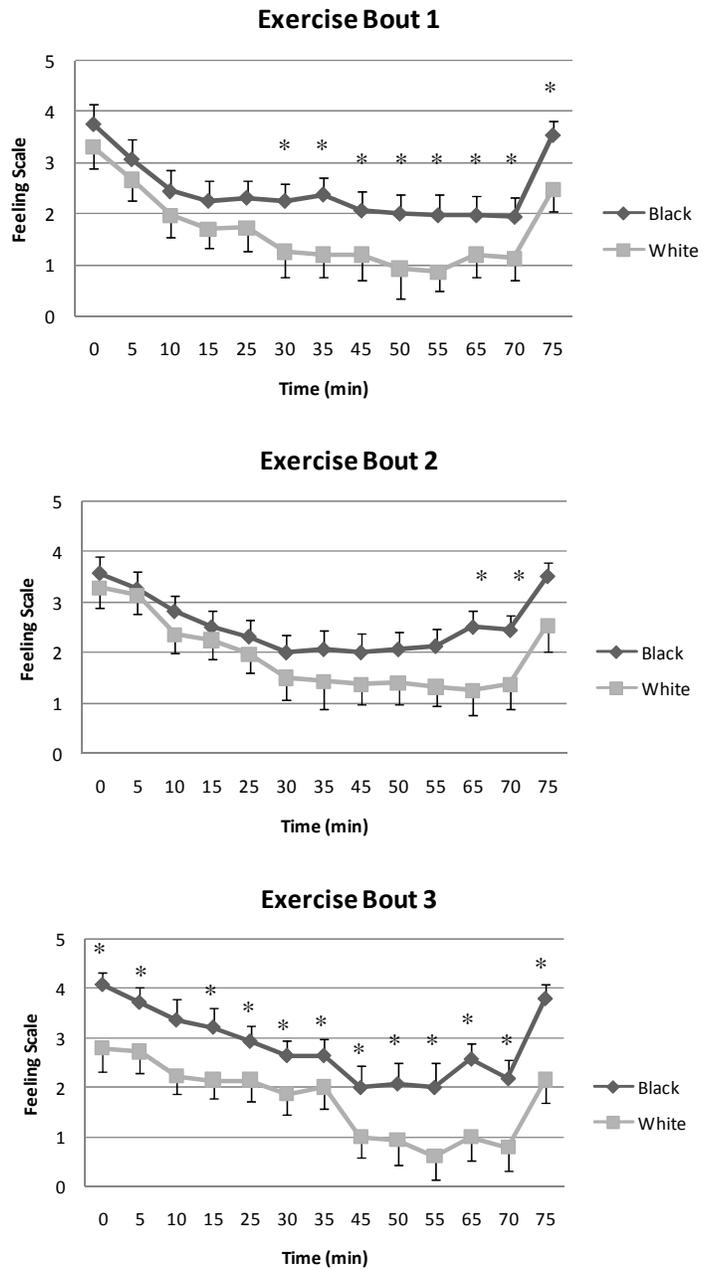


Figure 17. Rating of Perceived Exertion during Exercise. Mean \pm SE. *Significant effect of exercise at $p < 0.05$.

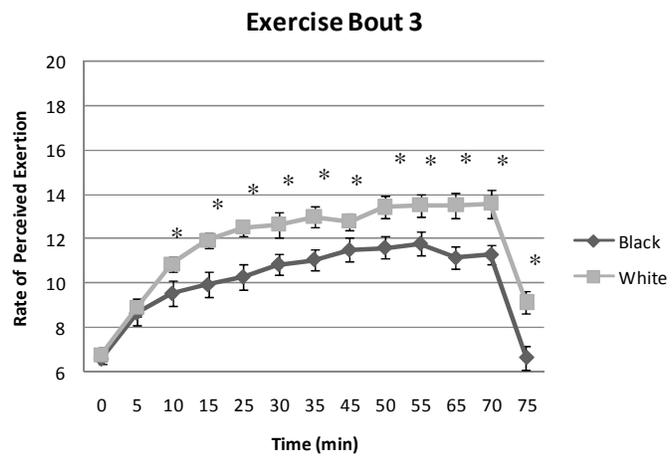
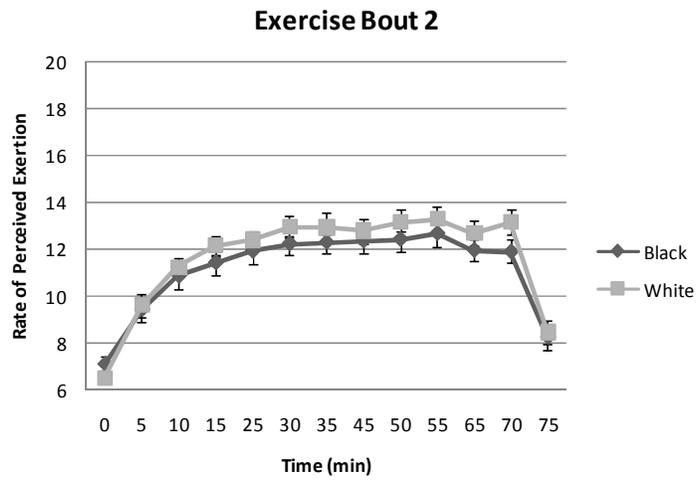
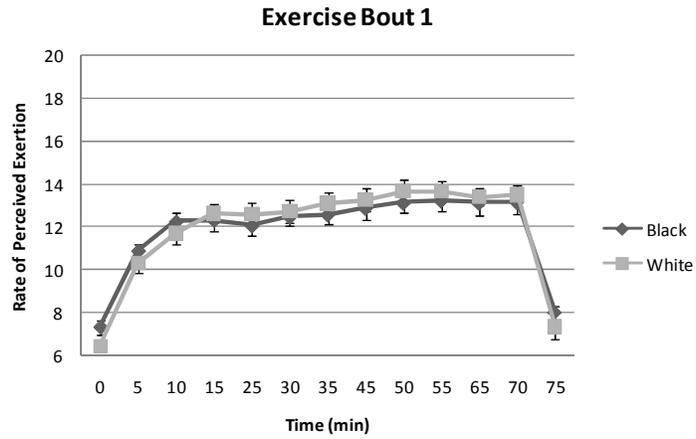
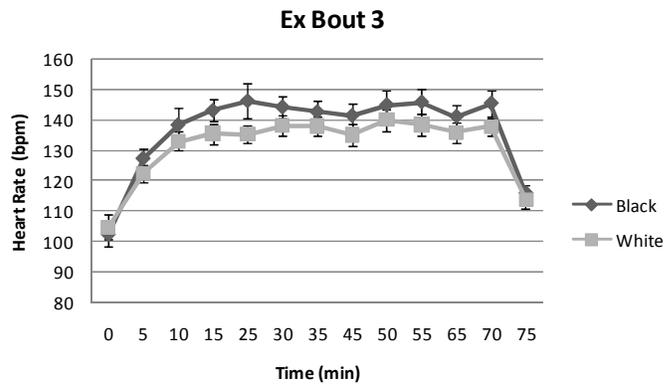
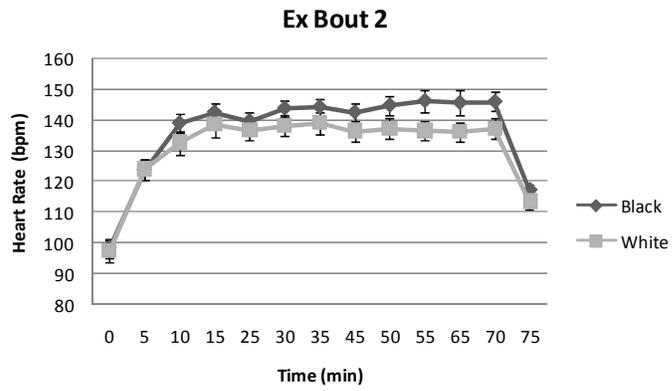
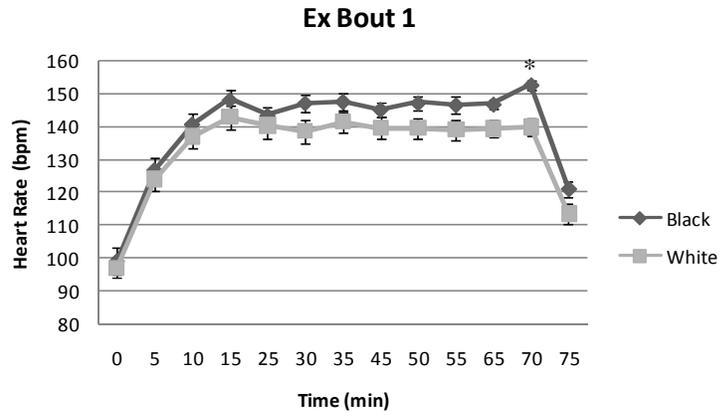


Figure 18. Heart Rate during Exercise. Mean \pm SE. *Significant effect of exercise at $p < 0.05$.



CHAPTER VI

LIMITATIONS AND FUTURE DIRECTIONS

Limitations

Generalizability: It is recognized that timeframe and resource constraints limit the findings of the present study to be more exploratory than definitive. By design, risk factors for diabetes (age, BMI, fat mass, habitual physical activity) and environmental determinants of exercise (level of education, neighborhood safety, lack of transportation, lack of access to facilities) were minimized to better examine ethnic/racial differences in the metabolic and psychosocial responses to exercise. Furthermore, the use of black and white college students and faculty from the University of Massachusetts increased the internal validity by minimizing inter-individual variability but reduced the external validity because the study environment cannot be generalized to other environments. Results from this dissertation project will provide the necessary empirical information to design larger, more comprehensive studies with actual incidence or prevalence of Type-2 diabetes as the outcome and craft more appropriate strategies to use physical activity as a tool to prevent/manage Type 2 diabetes in non-Hispanic black populations.

Individual bouts of exercise vs. habitual training: It is recognized that a single bout of exercise does not reflect the adaptations seen with chronic (weeks/months) exercise training. A body of research has documented that the majority of the improvements in insulin sensitivity are transient effects of recent exercise and are lost 24-74 hours post-exercise. As described earlier, the concept of exercise as a drug (i.e. each individual dose is important) supports a focus on how to optimize both the metabolic effects (e.g. enhanced insulin sensitivity) and the psychosocial effects (e.g. improved mood, self-efficacy) garnered after each exercise bout. Enhancing the improvements

associated with individual bouts of exercise can maximize the efficacy of each exercise dose and the probability that the subsequent exercise dose will be taken.

Impact of diet: By design, the contribution of dietary energy balance, macronutrient composition, or other nutritional factors to ethnic/racial disparities in insulin resistance and risk for Type 2 diabetes were not being addressed in this study. Nevertheless, previous research does not support the hypothesis that blacks consume more food compared to their white counterparts (49). To minimize the confounding impact of those factors on the outcomes of interest in the current study, all food was provided for subjects using standardized meals in the 12 hours prior to each blood measurement. Overall, the emphasis was placed on maintaining habitual levels of physical activity and dietary intake during participation in this study.

Control of exercise conditions: In general, few investigators have maintained strict control over the environmental and other contextual factors that could conceivably impact the psychosocial responses to exercise. Some of the most obvious factors such as: room temperature and humidity, visual and auditory stimuli, between subject and investigator, time of day and day of the week were controlled for in this study. Nevertheless, it is recognized that there are likely myriad other factors that contribute to the psychosocial response to exercise that the researchers are not aware of.

Concordance of Ethnicity/Race Between Researcher and Participant: In a health care setting, the concordance of race/ethnicity between patient and provider has been shown to influence patient's perception of quality care (23). Specifically, patient-provider relationship factors, such as interpersonal communication, trust, and mutual understanding of cultural differences in health needs and expectations are affected by the

race and ethnicity of both patients and providers. A recent study of disparities in quality of care suggests that minority patients are frequently dissatisfied with their interactions with physicians and report difficulties communicating effectively because of language or cultural issues (23). Several studies have shown that race/ethnicity concordance is positively associated with aspects of care for adults, such as participatory decision making, interpersonal respect, and satisfaction (23, 81). Based on these findings, the race/ethnicity of the investigator was matched with the race of the black participants in the present study. The effect of race/ethnicity concordance in white participants/patients has not yet been studied however it is possible that the race/ethnicity could have influenced the psychosocial responses to exercise in the white participants. In a subset of participants, black (n = 3) and white (n = 3) participants had a white investigator oversee at least one exercise session. There was no apparent influence of the race of the investigator in the black participants. In the white participants two participants had a slightly higher in-task mood score (third bout) when the race of the investigator was white, and one participant had a lower in-task mood score (second bout). Based on the small sample size, statistical comparisons were not conducted to examine the effects of race concordance on psychosocial responses to exercise but the examples mentioned strongly suggest no obvious influence.

Metabolic and psychosocial responses to single exercise bouts have strong implications for both the reduction in insulin resistance (28, 43) and the probability that an individual will continue to exercise (6). Therefore, both behavioral and metabolic factors related to physical inactivity may contribute to the increased prevalence of Type 2 diabetes in black populations. It is unknown whether blacks are at higher risk for diabetes

compared to whites because they are doing less physical activity (i.e., different exercise dose) or responding differently to the same physical activity stimulus (i.e., different exercise response). This dissertation project was designed to answer the later of these two questions. Specifically, the primary aim was to compare the metabolic and psychosocial responses to individual bouts of exercise in blacks and age/gender/BMI-matched whites. It was predicted that the effect of exercise to enhance insulin sensitivity during a hyperinsulinemic-euglycemic clamp would be smaller in blacks compared to whites. In addition, exercise would have a smaller effect to enhance fasting fat oxidation and insulin-stimulated carbohydrate oxidation in blacks compared to whites. Furthermore, it was hypothesized that the positive psychosocial effects of individual bouts of exercise on exercise task self-efficacy, state anxiety, and mood would be smaller in blacks compared to whites. The major findings of this project are listed below:

- There were no ethnic/racial differences in baseline measures of whole-body insulin sensitivity assessed by the hyperinsulinemic-euglycemic clamp.
- Black participants demonstrated larger improvements in the insulin sensitivity response to individual bouts of exercise compared to their white counterparts which was primarily the result of enhanced non-oxidative glucose disposal during the clamp.
- Blacks demonstrated a greater capacity to switch from primarily fat oxidation at rest to primarily carbohydrate oxidation during the clamp.
- There were no ethnic/racial differences in the psychosocial response to individual bouts of exercise; individual bouts of exercise improved exercise task self-efficacy and reduced psychological distress in both black and white participants.

- Black participants reported higher positive in-task mood during all three bouts of exercise and lower RPE scores during the third exercise bout compared to white participants, despite similar heart rates in both groups.

These data suggest that metabolic and psychosocial responses to individual bouts of exercise do not contribute to the increased insulin resistance and lower adherence rates to exercise programs reported in blacks compared to whites. If these results are confirmed in a larger, more diverse, free-living population, future research should focus on environmental constructs of Social Cognitive Theory (e.g., perceived neighborhood safety, lack of transportation/facilities, caregiving duties, etc.) to address the underlying mechanisms of lower adherence to exercise programs in black populations. To address the underlying mechanisms of increased insulin resistance in blacks, future research should examine environmental determinants that have a detrimental effect on glucose metabolism. Specifically, the metabolic effects of overfeeding are understudied in this population. Because blacks do not appear to exhibit impairments in the metabolic responses to exercise or energy deficit, future research should examine the metabolic response to overfeeding or energy surplus situations. Periods of caloric-induced energy surplus significantly increase insulin resistance (42). To date no study has directly examined ethnic/racial differences in the response to periods of energy surplus and energy deficit between blacks and whites, despite an increased prevalence of obesity in this ethnic minority population.

As a final point, to truly address ethnic/racial disparities in diabetes prevalence researchers need to shift their focus from changing health behaviors to changing social determinants to good health. The causal relationships between well-established risk

factors (such as physical activity and obesity), socioeconomic status, and insulin resistance between blacks and whites needs further investigation to better understand how we can effectively decrease the disparity in diabetes. These relationships are critical in planning prevention strategies. Traditionally and in this study, we have emphasized a model in which the risk factors of age, excess weight, and physical inactivity are primary. In an alternate model, however, low income and its associated factors may be primary factors that lead to stress adaptations such as smoking, high blood pressure, physical inactivity and excess energy intake. Based on the first model, public health programs have generally targeted such factors as obesity and physical inactivity, but adoption of the alternative model might lead to intervention through social programs and policies that successfully enhance the health status of all Americans in this country.

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