Strength Training and Insulin Resistance: The Mediating Role of Body Composition

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Strength Training and Insulin Resistance: The Mediating Role of Body Composition

McKayla Jean Niemann

A thesis submitted to the faculty of
Brigham Young University
in partial fulfillment of the requirements for the degree of

Master of Science

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ABSTRACT

Strength Training and Insulin Resistance: The Mediating Role of Body Composition

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Master of Science

OBJECTIVE: The main objective of the present study was to assess the association between varying amounts of strength training and insulin resistance. Another goal was to assess the influence of several potential confounding variables on the strength training and insulin resistance relationship. Lastly, the role of waist circumference, fat free mass, and body fat percentage on the association between strength training and insulin resistance was assessed.

METHODS: This cross-sectional study included 6561 randomly selected men and women in the US. Data were collected using the precise protocol established by NHANES. HOMA-IR was used as the outcome variable. Both time spent strength training and frequency of strength training bouts were used as exposure variables.

RESULTS: There was not a statistically significant relationship between strength training and insulin resistance in women. However, after controlling for 10 potential confounding variables, men who reported no strength training had significantly higher levels of HOMA-IR compared to men who reported moderate or high levels of strength training (F = 9.87, P < 0.0001). Odds ratios were also assessed, and 10 potential confounding variables were controlled. Men reporting no strength training had 2.42 times the odds of having insulin resistance compared to men reporting moderate levels of strength training (95% CI: 1.19 to 4.93). Similarly, men reporting no strength training had 2.50 times the odds of having insulin resistance compared to men reporting high levels of strength training (95% CI: 1.25 to 5.00).

CONCLUSION: There was a strong relationship between strength training and insulin resistance in US men, but not in US women. Differences in waist circumference, fat free mass, and body fat percentage, as well as demographic and lifestyle measures, do not appear to mediate the relationship.
ACKNOWLEDGEMENTS

First, I want to express my appreciation to Dr. Tucker for his mentorship. Specifically, the time and energy he spent teaching me, editing the present investigation, and assisting me in statistical analyses. I also appreciate Dr. Bailey and Dr. Davidson for their mentorship and their contributions to the design and editing of this investigation. Lastly, to my husband, Jeff, for his assistance with formatting.
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INTRODUCTION

The Centers for Disease Control and Prevention (2017) estimates that 30.3 million people in the US have diabetes, over 9% of the population.\(^1\) Another 84.1 million adults are prediabetic, 33.9% of the adult population. Currently, diabetes is the seventh leading cause of death in the US.\(^1\) Type 2 diabetes is also a major risk factor for coronary heart disease, the leading cause of mortality in the US.\(^1\) It is also a significant predictor of stroke,\(^1-3\) atrial fibrillation,\(^3,4\) and lower-extremity amputation.\(^1\)

Insulin resistance is a precursor to diabetes. People who are insulin resistant need greater amounts of insulin to get glucose into their cells.\(^5\) If not corrected through physical activity, weight loss, and/or prescribed medication, insulin resistance frequently leads to type 2 diabetes.

Ample evidence suggests that physical activity can help prevent and treat insulin resistance and type 2 diabetes.\(^6\) Physical activity lowers glucose levels in the blood by activating GLUT-4 vesicles, which transport glucose into the cells.\(^7\) Studies indicate that the increase in insulin sensitivity due to physical activity is an acute effect, only lasting a day or two after an exercise bout.\(^7\) However, physical activity for people who are insulin resistant may help decrease their likelihood of developing type 2 diabetes.\(^8\)

Several investigations indicate that aerobic activities, such as jogging, walking, and cycling, reduce the risk of type 2 diabetes.\(^9,10\) However, far less research has been conducted on the relationship between strength training and insulin resistance. Strength training could be a favorable exercise option, especially for people with comorbid diseases, such as obesity or cardiac disease, which can make aerobic exercise challenging.

To date, a few investigations have shown an inverse, linear relationship between strength training and insulin resistance.\(^11-13\) Some of the studies indicate that the relationship between
strength training and insulin resistance is due to the body mass effect, which suggests that the muscle hypertrophy gained from strength training increases insulin sensitivity.\textsuperscript{13,14} However, other studies examining the mass effect have concluded that there is not a significant relationship between the increase in muscle mass due to strength training and insulin resistance.\textsuperscript{15,16} Additionally, some research indicates that differences in waist circumference have a meaningful influence on the strength training and insulin sensitivity relationship,\textsuperscript{17} whereas other research does not support the mediating role of abdominal obesity.\textsuperscript{18}

Due to inconsistent findings and limited research, additional investigations are needed to assess the relationship between strength training and insulin resistance. Investigations designed to study the mediating effect of body composition, particularly fat-free mass and waist circumference, on the relationship between strength training and insulin resistance are especially needed.

The primary objective of the present study was to determine the extent to which varying amounts of strength training account for differences in insulin resistance in a nationally representative sample of US women and men. Hence, the findings are generalizable to all noninstitutionalized adults residing in the United States. Another purpose was to determine the contribution of several potential confounding variables, including age, gender, race, year of assessment, smoking, body mass index, and participation in physical activities other than strength training, on the strength training and insulin resistance association. Lastly, and of particular interest, was the extent to which the relationship between strength training and insulin resistance was influenced by differences in body composition, particularly waist circumference, body fat percentage, and fat-free mass.
METHODS

Design

A cross-sectional study using NHANES data was conducted. NHANES, the National Health and Nutrition and Examination Survey, is an extensive ongoing survey of health and nutrition information conducted by the National Center for Health Statistics. The National Center for Health Statistics is a part of the US Centers for Disease Control and Prevention. Due to the use of fasting blood glucose and fasting insulin values to calculate HOMA-IR in the present study, and because NHANES has measured these key variables using different methods over the years, the present study focused on 8 years of NHANES data, from 1999 to 2006. Data for these 8 years were collected in 2-year cycles, and the glucose and insulin values were equated using NHANES regression models. Additional details pertaining to the methods used in the collection of NHANES data are available online.19

Each survey participant submitted a written informed consent form to NHANES prior to data collection.20 The Ethics Review Board for the National Center for Health Statistics (previously referred to as The Institutional Review Board) approved the NHANES data collection.20 The Ethics Review Board also allowed the data files to be posted on the NHANES website for public use.20

Subjects

A total of 6561 participants were included in the present study. NHANES data were collected using a multistage random sample of noninstitutionalized people in the United States. The present investigation included participants ages 20 to 84. Although data were collected by NHANES on individuals older than 84 years, all subjects 85 years and older were given the age of 85 by NHANES to maximize confidentiality. Hence, these participants were not included in
the current investigation. Each of the participants included had data on age, gender, race, year of assessment, HOMA-IR, minutes and sessions of strength training performed per week, MET-minutes of physical activity other than strength training, smoking status, BMI (body mass index), waist circumference, body fat percentage, and fat-free mass.

Instrumentation and Measurement Methods

Race. NHANES classified race into 5 categories: Non-Hispanic White, Non-Hispanic Black, Mexican American, Other Race, and Other Hispanic.

HOMA-IR. In the present investigation, insulin resistance was the outcome variable. HOMA-IR was used to index insulin resistance. The formula to calculate HOMA-IR was: 

\[
\text{HOMA-IR} = \frac{\text{fasting insulin (μU/mL) × fasting glucose (mg/dL)}}{405}
\]

HOMA-IR is a common method of assessing insulin resistance. A literature search shows that over 22,000 studies use the term HOMA or HOMA-IR in their publications. People with diabetes were not included in the study. Additionally, adults who were unable to give a blood sample, including those who had chemotherapy within 4 weeks, hemophiliacs, people with rashes, burns, edema, or paralysis were not included. \(^21\)

Fasting insulin and fasting glucose information was obtained from NHANES data sets. Participants were asked to fast for 9 hours prior to coming in for testing. Before the blood sample, participants filled out a fasting survey that asked specific questions addressing the last time they had consumed food or liquids. Included in the questionnaire were questions specific to the ingestion of less commonly thought of foods such as breathe mints, gum, tea, alcohol, or supplements to ensure that the participants were following the fasting protocol. Blood samples of 89 to 92 ml were collected.
Strength Training. The present study had 2 exposure variables, total minutes of strength training per month and sessions of strength training per month. NHANES reported sessions of strength training per month, which was equivalent to days of strength training per month for the vast majority of the participants. A value of 4.3 weeks per month was used to convert monthly values to weekly for ease of interpretation (365 ÷ 12 = 30.4; 30.4 ÷ 7 = 4.3). Minutes of strength training per week was treated as a categorical variable. Adults who reported 10 minutes or less of strength training per week were put into a nonstrength training group. Adults who engaged regularly for at least 10 minutes of strength training per week were divided into 3 categories based on the amount of time they trained per week—Low: 11 to 59 minutes per week; Moderate: 60 to 119 minutes per week; High: 120 minutes or more per week. The second exposure variable, sessions per week of strength training, was also treated as a categorical variable. Adults were divided into 4 groups: 0 to 1 session per week, 2 sessions per week, 3 sessions per week, and 4 or more sessions per week.

Other Physical Activity. Many people who participate in strength training also participate in other forms of physical activity (PA), which is why the present study used physical activity other than strength training as a covariate. NHANES collected frequency, duration, and intensity data on 47 physical activities other than strength training. Each PA was converted to MET-minutes and then added together to index total MET-minutes of other physical activity.

MET units are useful for describing energy expenditure from a specific activity and for comparing energy expenditure across multiple activities. A MET represents the ratio between a person’s metabolic rate during physical activity and their metabolic rate at rest. To calculate MET-minutes, the MET value of an activity was determined and was multiplied by the time spent engaged in the activity.
**Smoking.** Smoking was indexed using pack-years. Pack-years are frequently used as an index of the amount an adult has smoked over several years. It is calculated by multiplying the number of years the person has smoked by the number of packs of cigarettes smoked per day. That number is then divided by 20, which is the amount of cigarettes in each pack. Smokers are more likely to develop insulin resistance than nonsmokers, which is why pack-years was used as a covariate in the present investigation.

**Height and Weight.** Height was measured with each adult’s heels, buttocks, shoulder blades, and back of the head against a wall. The feet were flat on the floor with the toes angled outwards. A stadiometer was then used to measure standing height.

Participants were weighed on a digital Toledo scale. When being weighed, participants were only wearing underwear, a disposable paper gown, and foam slippers. Weight was recorded in pounds and then converted into kilograms. Both height and weight were used in the study to calculate BMI.

**Body Mass Index.** BMI is a common measure of body weight independent of height. It is calculated as weight in kilograms divided by height in meters squared. It is frequently used as a measure of obesity. BMI is a good predictor of insulin resistance. Hence, BMI was used as a covariate in the present study. BMIs less than 18.5 are considered underweight. Normal weight BMIs are more than 18.5 and less than 25, whereas overweight BMIs are between 25 and less than 30. BMIs signifying obesity are 30 or greater.

**Waist Circumference.** Waist circumference was measured by finding the superior lateral iliac crest of the pelvis. The NHANES examiner then took one measurement at the iliac crest, holding the measuring tape parallel to the floor. The measurement was taken to the nearest .1 cm after one normal exhalation of the participant. A steel measuring tape was put against the
skin tightly, but without folding the skin. Waist circumference was used as a covariate in the present investigation because it is strongly correlated with insulin resistance.\textsuperscript{26}

\textit{Body Fat Percentage.} Body fat percentage was measured using DXA, dual-energy x-ray absorptiometry. DXA scans measure total body fat, lean muscle mass, and bone density. Women who were pregnant were not scanned. Also, due to the size of the scanner and room limitations, people who were over 6’5” or over 300 pounds were also not scanned. NHANES used multiple imputation to fill in the missing data. More information regarding how NHANES used multiple imputation can be found on the NHANES website.\textsuperscript{22} Body fat percentage was used to calculate fat-free mass in this study.

\textit{Fat-Free Mass.} Fat-free mass represents the amount of mass a person has that is not adipose tissue. It was calculated by subtracting fat mass from total mass. In most adults, fat-free mass is mostly muscle, although it also includes bone and connective tissue. Typically, the more adults participate in strength training, the more fat-free mass they have. Fat-free mass was used in this study because several investigations suggest that fat-free mass might play a critical role in the relationship between strength training and insulin resistance.\textsuperscript{12–14,27}

Data Analysis

The NHANES sample that was used to generate the results of the present study was unique because participants were randomly selected from the adult population of the US. Therefore, findings of the present investigation can be generalized to the noninstitutionalized, civilian population because each participant was assigned a person-level sample weight. The sample weights, along with randomly selected strata and clusters, were included as part of each statistical analysis.
Given the large sample that was used in the present investigation, it is commonly assumed that the statistical power associated with each analysis is very high. However, this is not the case. Because of the multilevel sampling strategy used to acquire participants, the total number of degrees of freedom in the denominator for each analysis was only 59, derived by subtracting the 28 strata from the 57 clusters. In short, because of nesting, statistical power associated with the present study was moderate, at best.

Continuous variables were reported in the Results as means ± standard errors (SE). Outcomes for categorical variables were given as frequencies expressed as percentages ± SE. The descriptive statistics were determined using SurveyMeans and SurveyFreq, respectively.

HOMA-IR was the outcome variable for this cross-sectional investigation. There were two main exposure variables: 1) total minutes of strength training per month and 2) sessions of strength training per month. Minutes per month and sessions per month were converted to minutes per week and sessions per week at times for easier interpretation. Minutes per week of strength training was treated as a categorical variable with four levels. Specifically, subjects were assigned to Group 0 if they reported 10 minutes per week or fewer of strength training. Group 1 included those reporting > 10 minutes and < 60 minutes per week. Group 2 included adults with ≥ 60 minutes per week and < 120 minutes per week. Group 3 included participants who reported ≥ 120 minutes per week of strength training. Sessions per week of strength training were also treated as a categorical variable. Participants were assigned to one of four categories: 0 to 1 session per week; 2 sessions per week, 3 sessions per week, and 4 or more sessions per week of strength training.

The SurveyReg procedure was employed to determine the extent to which mean HOMA-IR levels differed across the strength training categories using multiple regression. To measure
the extent to which mean HOMA-IR levels across the strength training categories were influenced by potential confounding factors including age, sex, race, year of assessment, smoking, BMI, other physical activity, waist circumference, body fat percentage, and fat-free mass, partial correlation was used. The covariates were controlled sequentially, first evaluating the effect of the demographic factors considered together, then the lifestyle variables were added to the model, and finally waist, body fat percentage, and fat-free mass were included in the model. To create adjusted means, the least squares means procedure was used.

In another set of analyses, odds ratios were generated using SurveyLogistic to determine the odds of being insulin resistant (HOMA-IR ≥ 3.0) based on minutes of strength training per week. Effects of the demographic, lifestyle, and body composition covariates were also assessed.

For statistical significance, alpha was set at < 0.05 and all p-values were two-sided. To perform the statistical analyses, SAS version 9.4 was utilized (SAS Institute, Inc., Cary, NC, USA).

RESULTS

NHANES sample weights were used in this study so that the findings are generalizable to men and women in the US. In the present sample of 6561 participants, the average HOMA-IR ± SE was 1.6 ± 0.03. Among adults who reported at least 10 minutes of strength training per week, the average number of strength training sessions per month was 12.0 ± 0.8 (2.8 ± 0.2 per week), and the mean number of minutes spent strength training per month was 284.7 ± 26.1 (66.2 ± 6.1 per week). Table 1 further details characteristics of the sample of US men and women used in this study.

Table 2 displays the mean differences in HOMA-IR and the amount of strength training participation between men and women. On average, the mean HOMA-IR ± SE was greater
among the men than the women ($F = 35.58, P < 0.0001$). The average number of strength
training sessions per month ($F = 26.24, p < 0.0001$) and the mean number of minutes spent
strength training per month ($F = 51.19, P < 0.0001$) were both higher among the men than among
the women. After the sample was delimited to strength trainers, the average number of minutes
spent strength training per month was also higher among the men than among the women
($F = 34.69, P < 0.0001$). Overall, the relationship between HOMA-IR and amounts of strength
training was only significant in men, which is why Tables 3 and 4 focus on men only.

Sessions per week of strength training was significantly related to HOMA-IR in men.
Specifically, men who reported strength training 1 or fewer sessions per week had significantly
higher mean HOMA-IR levels than men who trained 2, 3, or 4 or more sessions per week. Mean
differences were significant when the demographic variables were controlled ($F = 12.0,
P < 0.0001$), and after adjusting for differences in the demographic covariates and the lifestyle
covariates together ($F = 11.3, P < 0.0001$). With the body composition factors added to the other
covariates, the relationship was weakened, but differences remained significant between men
who trained 1 session or less per week compared to the others ($F = 8.0, P = 0.0002$). HOMA-IR
means did not differ among men reporting strength training 2, 3, or 4 or more sessions per week.

Table 3 shows the odds of being insulin resistant (HOMA-IR $\geq 75^{th}$ percentile) in men
who reported < 10 minutes of strength training per week compared to men who reported low,
moderate, or high levels of strength training per week. After controlling for the demographic
covariates (age, race, and year of assessment), men who reported no strength training had 2.04
times the odds of being insulin resistant than men who reported a moderate level of strength
training (95% CI: 1.02 to 4.08). Men who reported no strength training had 2.18 times the odds
of being insulin resistant than men who reported a high level of strength training (95% CI: 1.24
to 3.86). Controlling for the demographic variables plus pack-years of smoking, other physical activity, and BMI increased the none vs moderate and none vs high odds ratios. Adding waist circumference to the covariates and then replacing waist circumference with fat-free mass or body fat percent had little effect on the odds ratios. Lastly, controlling for all the covariates together also had little effect on the odds ratios.

Table 4 shows the mean differences in HOMA-IR across categories of strength training in men. After adjusting for the demographic covariates (age, race, and year of assessment), mean HOMA-IR values differed significantly between the no-strength-training group and both the moderate-strength-training and high-strength-training groups (F = 11.40, P < 0.0001). After controlling for the demographic variables plus three lifestyle covariates (i.e., pack-years of smoking, other physical activity, and BMI), the relationship between HOMA-IR and strength training remained significant between the no-strength-training group and both the moderate-strength-training and high-strength-training groups (F = 13.88, P < 0.0001). After adding waist circumference to the demographic and lifestyle covariates, the relationship remained significant (F = 12.65, P < 0.0001). Replacing the covariate waist circumference with fat-free mass (F = 11.98, P < 0.0001) or body fat percent (F = 11.91, P < 0.0001) also resulted in a significant association. Lastly, all the covariates were controlled together. The relationship between strength training and HOMA-IR remained significant (F = 9.87, P < 0.0001).

DISCUSSION

The purpose of this study was 3-fold. First, to assess the extent to which varying levels of strength training account for differences in insulin resistance within a random sample of 6561 noninstitutionalized adults in the US. Second, to determine the influence of several mediating factors on the association between strength training and insulin resistance. Third, to evaluate the
extent that multiple measures of body composition influence the strength training and insulin resistance association.

Mean differences between men and women were evaluated. On average, men had higher HOMA-IR, a higher number of strength training sessions per month, and a higher number of minutes spent strength training each month than women. Due to the significant differences between women and men, the relationship between strength training and insulin resistance was studied separately.

There was not a significant relationship between strength training and insulin resistance in women. In contrast, results showed robust significance in men. The gender differences may be due to the varying levels of strength training between men and women. The Centers for Disease Control and Prevention reported that in the US, 21.5% of men and 17% of women participate in 2 or more days of strength training. Moreover, and of greater importance, according to the present study, men who strength trained reported about 6 hours and 20 minutes of resistive exercise per month, whereas women who strength trained reported about 4 hours per month. Similarly, the 75th percentile for minutes of strength training per month was almost 13 hours for men, whereas for women it was about 6 hours and 45 minutes, a large difference. Men participating in higher levels of strength training than women may be why the association between strength training and HOMA-IR was stronger in men than in women in the present study. There does not appear to be gender differences in physiological responses to strength training.

After controlling for the demographic covariates (age, race, and year of assessment), the results showed that men who reported < 10 minutes of strength training per week had about 2½ times the odds of having insulin resistance compared to those with moderate or high levels of
strength training. The results also indicated that the mean HOMA-IR values were significantly higher in the no-strength-training group compared to both the moderate-strength-training and high-strength-training groups. However, men reporting low levels of strength training did not differ from those reporting no strength training.

Controlling for the lifestyle covariates (ie, pack-years of smoking, other physical activity, and BMI), along with the demographic covariates, increased the none vs moderate and none vs high odds ratios. Also, the mean HOMA-IR values remained significantly different between the no-strength-training group and both the moderate-strength-training and high-strength-training groups.

There are multiple mechanisms that could account for the association between strength training and insulin resistance. The present investigation controlled for waist circumference, fat-free mass and body fat percentage to assess the potential mediating role of each variable. Controlling for the demographic and lifestyle covariates and adding waist circumference as a potential mediating factor had little effect on the association. The mean HOMA-IR values remained significantly higher in the no-strength-training group compared to both the moderate-strength-training and high-strength-training groups.

Other investigations have also found that waist circumference has no effect on the relationship between strength training and insulin resistance. Grotved et al conducted a cross-sectional study of 32 002 men from the Health Professionals Follow-Up Study. Weight training resulted in a 48% reduced risk of developing type two diabetes. Waist circumference weakened the correlation between strength training and type 2 diabetes, but the association remained statistically significant. Dunstan et al also considered the role of waist circumference in an 8-
week circuit training protocol on 27 individuals. It was concluded that circuit training decreased glucose levels independent of changes in waist circumference. A few studies have concluded that waist circumference plays a mediating role in the association between exercise and insulin resistance. However, most studies have assessed aerobic exercise, not strength training. For example, in a cross-sectional study Garcia-Hermoso et al concluded that waist circumference fully mediates the relationship between physical activity and HOMA-IR. Lee et al, who assessed resistance training along with aerobic training in a randomized controlled trial with 40 teenaged boys, found that changes in abdominal fat were significantly related to both resistance training and aerobic training and increased insulin sensitivity.

Adjusting for differences in the demographic and lifestyle covariates and adding fat-free mass as a potential mediator of the strength training and HOMA-IR association had little effect. Several studies support the present investigation’s finding. A quasi-experimental study including 28 overweight males who participated in a 12-week resistance training program found that, on average, the men increased in lean body mass. However, lean body mass did not appear to mediate the relationship between strength training and insulin resistance. Additionally, Anderson et al assessed insulin resistance after 90 days of training followed by 90 days of detraining. Changes in glucose clearance were expressed relative to muscle mass, measured using magnetic resonance imaging. Results showed that detraining increased insulin resistance and decreased fat-free mass. Anderson et al concluded that strength training was associated with decreases in insulin resistance and that fat-free mass did not play a role in the association. Lastly, Holten et al established a single-leg 6-week training program among 10 men with diabetes and 7 healthy age-matched controls. Results showed that glucose clearance increased
in the trained leg compared to the untrained leg in both the men with diabetes and the healthy controls.\textsuperscript{15} Muscle mass and fiber size did not increase significantly, therefore, it was concluded that strength training increases glucose clearance in the absence of changes in muscle mass.\textsuperscript{15}

There are a few studies suggesting that fat-free mass does mediate the relationship between strength training and insulin resistance. In a 6-month trial assessing both aerobic and strength training, Poehlman et al concluded that strength training increases insulin sensitivity by increasing fat-free mass.\textsuperscript{14} In a 16-week strength training study, results showed a decrease in insulin resistance and an increase in muscle fiber size, or hypertrophy, suggesting that the decrease in insulin resistance after 16 weeks of strength training was due to muscle hypertrophy.\textsuperscript{13} Hypertrophy may increase the amount of skeletal muscle tissue and GLUT-4 receptors.\textsuperscript{13,14} Given the mixed findings in the literature, additional research is needed to determine the mediating role of lean body mass or fat-free mass in the relationship between strength training and insulin resistance.

Controlling for the demographic and lifestyle covariates and adding body fat percentage to the model had little effect on the results. These findings are consistent with the literature. Poehlman et al assessed body fat percentage and insulin sensitivity in a 6-month exercise protocol and found no change in body fat percentage.\textsuperscript{14} It was concluded that body fat percentage does not mediate the relationship between strength training and insulin sensitivity. Moreover, in an 8-week trial, Dunstan et al did not see any changes in body fat percentage and reached a similar conclusion to Poehlman et al, that body fat percentage does not play a role in the strength training and insulin resistance association.\textsuperscript{33}

Theoretically, there are multiple mechanisms that could account for the association between strength training and insulin resistance, including waist circumference, fat-free mass,
and body fat percentage. However, findings of the present investigation failed to identify any of these factors as significant mediators. Other potential mechanisms, not measured in this study, could play a role. For example, the association could be due to increases in signaling proteins involved in glucose clearance because of strength training. Holten et al applied a single-leg resistance training intervention among 10 men and concluded that strength training decreased insulin resistance beyond the effects of fat-free mass.\textsuperscript{15} Holten et al measured several proteins and saw an increase in GLUT-4, protein kinase B, and glycogen synthase.\textsuperscript{15} Ahtiainen et al also used leg resistance training among men and found that resistance training increases signaling proteins.\textsuperscript{37} Specifically, Ahtiainen et al measured several proteins via muscle biopsy 30 minutes preexercise and 30 minutes postexercise and concluded that IRS-1 signaling is downgraded while the AMPK pathway is upregulated, which activates A160.\textsuperscript{37}

After controlling for all the covariates simultaneously, age, race, year of assessment, pack years of smoking, other physical activity, BMI, waist circumference, fat-free mass, and body fat percentage, the none vs moderate and none vs high levels of strength training odds ratios changed minimally. In short, men reporting moderate to high levels of strength training remained much less likely to be insulin resistant compared to their counterparts. Furthermore, the mean HOMA-IR values remained significantly higher and more unfavorable in the no-strength-training group compared to both the moderate-strength-training and high-strength-training groups. Apparently, if US men all had the same age, race, year of assessment, pack-years of smoking, other physical activity, BMI, waist circumference, fat-free mass, and body fat percentage, those reporting no regular strength training would tend to have more insulin resistance compared to their counterparts.
This study had several limitations. Strength training was self-reported so there could be misclassification of amounts of strength training, which could influence the findings. However, self-reporting is likely to weaken the association rather than strengthen it. Additionally, participants who reported high levels of strength training could have other lifestyle factors that are unique to them. Lastly, due to the cross-sectional design of this study, results cannot be interpreted as causal.

The study also had several strengths, including a large sample size of 6561. Ten potential confounding factors were assessed and controlled. Lastly, the results are generalizable to all noninstitutionalized men and women in the US due to the random selection of participants by NHANES.

In conclusion, levels of insulin resistance differed significantly between US men reporting no strength training and those reporting moderate or high levels of strength training. There was not a significant difference between US men reporting no strength training and those reporting low levels of strength training. Moreover, there was not a significant relationship between strength training and insulin resistance in US women. Even after adjusting for differences in numerous potential confounding factors, men reporting no strength training had about 2½ times the odds of having insulin resistance compared to men reporting either moderate or high levels of strength training. Finally, in the present study, the association between strength training and insulin resistance in US men was not influenced by differences in waist circumference, fat-free mass, or body fat percentage.
REFERENCES


Table 1. Percentiles for the key variables representing US women and men

<table>
<thead>
<tr>
<th>Variable</th>
<th>5th (± SE)</th>
<th>25th (± SE)</th>
<th>50th (± SE)</th>
<th>75th (± SE)</th>
<th>95th (± SE)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>HOMA-IR</strong></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Women (n = 3429)</td>
<td>0.3 ± 0.02</td>
<td>0.9 ± 0.02</td>
<td>1.5 ± 0.04</td>
<td>2.5 ± 0.07</td>
<td>5.6 ± 0.2</td>
</tr>
<tr>
<td>Men (n = 3132)</td>
<td>0.4 ± 0.02</td>
<td>1.0 ± 0.02</td>
<td>1.7 ± 0.03</td>
<td>3.0 ± 0.08</td>
<td>6.4 ± 0.3</td>
</tr>
<tr>
<td>Combined (n = 6561)</td>
<td>0.4 ± 0.01</td>
<td>0.9 ± 0.02</td>
<td>1.6 ± 0.03</td>
<td>2.8 ± 0.05</td>
<td>6.0 ± 0.2</td>
</tr>
<tr>
<td><strong>Waist Circumference (cm)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Women (n = 3429)</td>
<td>71.1 ± 0.3</td>
<td>80.7 ± 0.3</td>
<td>90.0 ± 0.5</td>
<td>102.1 ± 0.5</td>
<td>120.4 ± 1.1</td>
</tr>
<tr>
<td>Men (n = 3132)</td>
<td>76.6 ± 0.7</td>
<td>89.1 ± 0.4</td>
<td>97.5 ± 0.3</td>
<td>107.3 ± 0.5</td>
<td>124.5 ± 1.1</td>
</tr>
<tr>
<td>Combined (n = 6561)</td>
<td>72.8 ± 0.4</td>
<td>84.3 ± 0.3</td>
<td>94.2 ± 0.3</td>
<td>105.0 ± 0.4</td>
<td>122.4 ± 0.7</td>
</tr>
<tr>
<td><strong>Fat Free Mass (kg)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Women (n = 3429)</td>
<td>32.5 ± 0.2</td>
<td>37.8 ± 0.2</td>
<td>42.0 ± 0.2</td>
<td>47.1 ± 0.2</td>
<td>56.5 ± 0.5</td>
</tr>
<tr>
<td>Men (n = 3132)</td>
<td>47.0 ± 0.4</td>
<td>55.3 ± 0.3</td>
<td>61.2 ± 0.3</td>
<td>67.5 ± 0.3</td>
<td>79.1 ± 0.6</td>
</tr>
<tr>
<td>Combined (n = 6561)</td>
<td>34.4 ± 0.2</td>
<td>41.6 ± 0.2</td>
<td>50.8 ± 0.3</td>
<td>61.2 ± 0.3</td>
<td>74.3 ± 0.4</td>
</tr>
<tr>
<td><strong>Body Fat %</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Women (n = 3429)</td>
<td>28.7 ± 0.4</td>
<td>35.9 ± 0.2</td>
<td>41.2 ± 0.2</td>
<td>45.7 ± 0.2</td>
<td>51.3 ± 0.3</td>
</tr>
<tr>
<td>Men (n = 3132)</td>
<td>16.6 ± 0.3</td>
<td>23.7 ± 0.2</td>
<td>28.0 ± 0.2</td>
<td>32.2 ± 0.2</td>
<td>38.5 ± 0.3</td>
</tr>
<tr>
<td>Combined (n = 6561)</td>
<td>19.0 ± 0.3</td>
<td>27.6 ± 0.2</td>
<td>34.2 ± 0.4</td>
<td>41.8 ± 0.2</td>
<td>49.3 ± 0.3</td>
</tr>
<tr>
<td><strong>BMI (kg/m²)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Women (n = 3429)</td>
<td>19.4 ± 0.2</td>
<td>22.9 ± 0.1</td>
<td>26.5 ± 0.2</td>
<td>31.5 ± 0.25</td>
<td>40.6 ± 0.5</td>
</tr>
<tr>
<td>Men (n = 3132)</td>
<td>20.4 ± 0.1</td>
<td>24.2 ± 0.1</td>
<td>27.1 ± 0.1</td>
<td>30.4 ± 0.1</td>
<td>37.4 ± 0.5</td>
</tr>
<tr>
<td>Combined (n = 6561)</td>
<td>19.8 ± 0.1</td>
<td>23.5 ± 0.1</td>
<td>26.8 ± 0.1</td>
<td>31.0 ± 0.1</td>
<td>39.5 ± 0.4</td>
</tr>
<tr>
<td><strong>Other PA (min)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Women (n = 3429)</td>
<td>0.0 ± 15.7</td>
<td>0.0 ± 15.7</td>
<td>250.6 ± 29.8</td>
<td>1097.3 ± 65.2</td>
<td>3515.7 ± 160</td>
</tr>
<tr>
<td>Men (n = 3132)</td>
<td>0.0 ± 15.5</td>
<td>0.0 ± 15.5</td>
<td>439.9 ± 39.0</td>
<td>1466.8 ± 55.6</td>
<td>5123.6 ± 244</td>
</tr>
<tr>
<td>Combined (n = 6561)</td>
<td>0.0 ± 13.6</td>
<td>0.0 ± 13.6</td>
<td>328.2 ± 30.7</td>
<td>1259.9 ± 47.2</td>
<td>4392.8 ± 216</td>
</tr>
<tr>
<td><strong>ST sessions/month</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Women (n = 3429)</td>
<td>0.0 ± 0.9</td>
<td>0.0 ± 0.9</td>
<td>0.0 ± 0.9</td>
<td>0.0 ± 0.9</td>
<td>8.2 ± 1.3</td>
</tr>
<tr>
<td>Men (n = 3132)</td>
<td>0.0 ± 0.8</td>
<td>0.0 ± 0.8</td>
<td>0.0 ± 0.8</td>
<td>0.0 ± 0.8</td>
<td>12.5 ± 1.0</td>
</tr>
<tr>
<td>Combined (n = 6561)</td>
<td>0.0 ± 0.7</td>
<td>0.0 ± 0.7</td>
<td>0.0 ± 0.7</td>
<td>0.0 ± 0.7</td>
<td>12.0 ± 0.9</td>
</tr>
<tr>
<td><strong>ST min/month (min)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Women (n = 3429)</td>
<td>0.0 ± 5.0</td>
<td>0.0 ± 5.0</td>
<td>0.0 ± 5.0</td>
<td>0.0 ± 5.0</td>
<td>171.1 ± 30.2</td>
</tr>
<tr>
<td>Men (n = 3132)</td>
<td>0.0 ± 5.1</td>
<td>0.0 ± 5.1</td>
<td>0.0 ± 5.1</td>
<td>0.0 ± 5.1</td>
<td>527.9 ± 91.9</td>
</tr>
<tr>
<td>Combined (n = 6561)</td>
<td>0.0 ± 4.8</td>
<td>0.0 ± 4.8</td>
<td>0.0 ± 4.8</td>
<td>0.0 ± 4.8</td>
<td>273.1 ± 35.2</td>
</tr>
<tr>
<td><strong>ST sessions/month</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Women (n = 180)</td>
<td>2.1 ± 0.2</td>
<td>6.0 ± 1.0</td>
<td>8.9 ± 0.9</td>
<td>12.9 ± 0.9</td>
<td>21.0 ± 1.7</td>
</tr>
<tr>
<td>Men (n = 323)</td>
<td>1.5 ± 0.9</td>
<td>7.1 ± 0.9</td>
<td>12.2 ± 0.8</td>
<td>14.2 ± 0.8</td>
<td>26.7 ± 1.7</td>
</tr>
<tr>
<td>Combined (n = 503)</td>
<td>1.8 ± 0.1</td>
<td>7.0 ± 0.8</td>
<td>12.0 ± 0.8</td>
<td>13.0 ± 0.8</td>
<td>25.9 ± 1.6</td>
</tr>
<tr>
<td><strong>ST min/month (min)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Women (n = 180)</td>
<td>56.4 ± 0.0</td>
<td>129.5 ± 12.3</td>
<td>239.8 ± 20.2</td>
<td>404.4 ± 48.4</td>
<td>823.8 ± 55.2</td>
</tr>
<tr>
<td>Men (n = 323)</td>
<td>56.2 ± 0.0</td>
<td>187.2 ± 25.1</td>
<td>378.9 ± 33.4</td>
<td>776.0 ± 56.6</td>
<td>1555.5 ± 57</td>
</tr>
<tr>
<td>Combined (n = 503)</td>
<td>57.1 ± 1.8</td>
<td>150.1 ± 13.4</td>
<td>284.7 ± 26.1</td>
<td>603.5 ± 58.3</td>
<td>1523.4 ± 90</td>
</tr>
</tbody>
</table>

SE: standard error. Table values include person-level weighted adjustments based on the sampling methods of NHANES so that values represent those of the US adult population.

*The sample was delimited to individuals reporting at least 10 minutes of strength training per week (men: n = 323, women: n = 180).
<table>
<thead>
<tr>
<th></th>
<th>Men (n = 3132)</th>
<th>Women (n = 3429)</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>HOMA-IR</strong></td>
<td>Mean ± SE</td>
<td>Mean ± SE</td>
<td>F</td>
<td>P</td>
</tr>
<tr>
<td></td>
<td>2.61 ± 0.09</td>
<td>2.20 ± 0.07</td>
<td>35.58</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td><strong>ST sessions per month</strong></td>
<td>1.24 ± 0.12</td>
<td>0.59 ± 0.11</td>
<td>26.24</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td><strong>ST minutes per month</strong></td>
<td>64.95 ± 8.62</td>
<td>17.62 ± 5.29</td>
<td>51.19</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td><strong>ST sessions per month</strong>*</td>
<td>13.08 ± 0.56</td>
<td>12.32 ± 0.74</td>
<td>1.13</td>
<td>0.2900</td>
</tr>
<tr>
<td><strong>ST minutes per month</strong>*</td>
<td>638.58 ± 61.42</td>
<td>416.50 ± 51.55</td>
<td>34.69</td>
<td>&lt; 0.0001</td>
</tr>
</tbody>
</table>

SE: standard error. HOMA-IR: Homeostatic model assessment of insulin resistance. ST sessions per month: number of strength training sessions reported each month. ST min per month: minutes of strength training reported each month. Means have been adjusted for the covariates: age, race, and year of assessment. The F and P values are based on 59 degrees of freedom.

*The sample was delimited to individuals reporting at least 10 minutes of strength training per week (men: n = 323, women: n = 180).
Table 3. Odds of insulin resistance (HOMA $\geq$ 75th percentile) in men with no strength training compared to higher amounts of strength training

<table>
<thead>
<tr>
<th>Outcome: HOMA (75th percentile)</th>
<th>Variable Controlled</th>
<th>OR</th>
<th>95% CI</th>
<th>OR</th>
<th>95% CI</th>
<th>OR</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>None vs Low</td>
<td>Model 1</td>
<td>1.69</td>
<td>0.95–3.00</td>
<td>2.04</td>
<td>1.02–4.08</td>
<td>2.18</td>
<td>1.24–3.86</td>
</tr>
<tr>
<td>None vs Moderate</td>
<td>Model 2</td>
<td>1.62</td>
<td>0.84–3.11</td>
<td>2.69</td>
<td>1.33–5.46</td>
<td>2.95</td>
<td>1.48–5.89</td>
</tr>
<tr>
<td>None vs High</td>
<td>Model 3</td>
<td>1.57</td>
<td>0.82–3.00</td>
<td>2.55</td>
<td>1.26–5.13</td>
<td>2.64</td>
<td>1.33–5.28</td>
</tr>
<tr>
<td></td>
<td>Model 4</td>
<td>1.59</td>
<td>0.84–3.05</td>
<td>2.65</td>
<td>1.30–5.40</td>
<td>2.90</td>
<td>1.45–5.83</td>
</tr>
<tr>
<td></td>
<td>Model 5</td>
<td>1.55</td>
<td>0.81–2.95</td>
<td>2.45</td>
<td>1.19–5.04</td>
<td>2.60</td>
<td>1.31–5.16</td>
</tr>
<tr>
<td></td>
<td>Model 6</td>
<td>1.54</td>
<td>0.82–2.89</td>
<td>2.42</td>
<td>1.19–4.93</td>
<td>2.50</td>
<td>1.25–5.00</td>
</tr>
</tbody>
</table>

OR = odds ratio; odds of having insulin resistance (HOMA $\geq$ 75th percentile)
95% CI = 95% confidence interval.

For the categories representing minutes of strength training, None included men reporting < 10 minutes per week of strength training. Low included men reporting $\geq$ 10 minutes per week and < 60 minutes per week, moderate included men reporting $\geq$ 60 minutes per week and < 120 minutes per week, and high included men reporting $\geq$ 120 minutes per week.

Odds ratios on the same line as a model were adjusted for potential covariates in that model. For example, in Model 1 after adjusting for covariates, men with no strength training had 2.18 times the odds (OR = 2.18) of having insulin resistance compared to men who reported 120 minutes or more of strength training.

Model 1 included age, race, and year of assessment as covariates. Model 2 included age, race, year, pack-years of smoking, other physical activity and BMI. Model 3 included the same covariates as Model 2 plus waist circumference. Model 4 included the same covariates as Model 2 plus fat-free mass. Model 5 included the same covariates as Model 2 plus body fat percent. Model 6 included the same covariates as Model 2 plus waist circumference, fat-free mass, and body fat percent.
Table 4. Mean differences in HOMA-IR in men across categories of strength training based on minutes of participation after adjusting for potential confounders

<table>
<thead>
<tr>
<th>Outcome Variable</th>
<th>Minutes of Strength Training</th>
<th>Mean</th>
<th>SE</th>
<th>Mean</th>
<th>SE</th>
<th>Mean</th>
<th>SE</th>
<th>Mean</th>
<th>SE</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>None</td>
<td></td>
<td></td>
<td>Low</td>
<td></td>
<td>Moderate</td>
<td></td>
<td>High</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>None</td>
<td>2.59</td>
<td>0.12</td>
<td>2.24</td>
<td>0.36</td>
<td>1.96</td>
<td>0.21</td>
<td>1.94</td>
<td>0.20</td>
<td>11.40</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>2.62</td>
<td>0.08</td>
<td>2.37</td>
<td>0.32</td>
<td>2.00</td>
<td>0.17</td>
<td>1.94</td>
<td>0.12</td>
<td>13.88</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td></td>
<td>Moderate</td>
<td>2.66</td>
<td>0.09</td>
<td>2.45</td>
<td>0.32</td>
<td>2.07</td>
<td>0.17</td>
<td>2.10</td>
<td>0.11</td>
<td>12.65</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>2.61</td>
<td>0.07</td>
<td>2.37</td>
<td>0.32</td>
<td>2.01</td>
<td>0.16</td>
<td>1.95</td>
<td>0.10</td>
<td>11.98</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td></td>
<td>Model 4</td>
<td></td>
<td></td>
<td>Mean</td>
<td></td>
<td>Mean</td>
<td></td>
<td>Mean</td>
<td></td>
<td>F</td>
<td>P</td>
</tr>
<tr>
<td></td>
<td>Model 5</td>
<td>2.62</td>
<td>0.08</td>
<td>2.38</td>
<td>0.32</td>
<td>2.03</td>
<td>0.17</td>
<td>2.00</td>
<td>0.12</td>
<td>11.91</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td></td>
<td>Model 6</td>
<td>2.64</td>
<td>0.08</td>
<td>2.49</td>
<td>0.32</td>
<td>2.11</td>
<td>0.16</td>
<td>2.12</td>
<td>0.10</td>
<td>9.87</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

a,b Means on the same row with the same superscript letter are not significantly different (p > 0.05)
SE = standard error of the mean.
Means have been adjusted according to the covariates included in the model. Model 1 included age, race, and year of assessment as covariates. Model 2 included age, race, year, pack-years of smoking, other physical activity and BMI. Model 3 included the same covariates as Model 2 plus waist circumference. Model 4 included the same covariates as Model 2 plus fat-free mass. Model 5 included the same covariates as Model 2 plus body fat percent. Model 6 included the same covariates as Model 2 plus waist circumference, fat-free mass, and body fat percent.
For the categories representing minutes of strength training, None included men reporting < 10 minutes per week of strength training. Low included men reporting ≥ 10 minutes per week and < 60 minutes per week, Moderate included men reporting ≥ to 60 minutes per week and < 120 minutes per week, and High included men reporting > 120 minutes per week.