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PHYSICAL ACTIVITY AND HEALTH

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ABSTRACT

While the link between physical activity and health has been studied, there are several limitations that persist in this literature relating to external and internal validity of the estimates, potential measurement error in self-reported weight and risk factors, failure to account for physical activity beyond exercise, and failure to separate the effects of exercise from other forms of physical activity. This study addresses these gaps and assesses plausibly causal effects of recreational exercise and other physical activity (including work-related activity) on the risk factors for heart disease, utilizing a population-based longitudinal dataset that contains objective information on key risk factors. We estimate fixed effects specifications that account for a host of unobservable confounding factors, and further estimate specifications with lagged outcome measures that allow us to bound plausibly causal effects under reasonable assumptions. There are four key patterns of results that emerge. First, the lagged effect of physical activity is almost always larger than the current effect. This suggests that current risk factors, not only obesity but also high blood pressure and heart rate, take years to develop, which underscores the importance of consistent physical activity to ward off heart disease. Second, we find that in general physical activity reduces risk factors for heart disease even after controlling, to some extent, for unobservable confounding influences. Third, not only recreational but work-related physical activity appears to protect against heart disease. Finally, there is evidence of a dose-response relationship such that higher levels of recreational exercise and other physical activity have a greater protective effect. Our estimates of the contemporaneous and durable effects suggest that the observed declines in high levels of recreational exercise and other physical activity can potentially account for between 12-30% of the increase in obesity, hypertension, diabetes, and heart disease observed over the sample period, ceteris paribus.

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1. Introduction

A comprehensive report of the U.S. Surgeon General (U.S. Department of Health and Human Services 1996) concluded that physical activity ameliorates many of the risk factors for heart disease, such as obesity, high blood pressure, and a rapid pulse, as well as reduces the incidence of diseases such as Type 2 diabetes, angina, heart attack, and stroke with which they are associated. However, the studies upon which these conclusions rest suffer from a number of weaknesses. While the effects found in randomized controlled studies are plausibly causal, they may lack external validity since these studies are based on small, convenience samples of persons whose behavior may not generalize to the overall population (Stamler et al. 1989; Arroll and Beaglehole 1992; Kelley and McClellan 1994). In contrast, studies that have utilized population-based samples generally do not control for the many confounding factors that affect both physical activity as well as health, and thus it is not clear whether their results can be considered causal (Arraiz, Wigle, Mao 1992; Sherman et al. 1994; Hu et al. 2007). Thus, these studies often lack internal validity. In addition, the population-based samples used in these studies mainly contain *self-reported* rather than objectively-measured characteristics, such as height, weight, and the presence of high blood pressure, which may be subject to systematic misreporting or under-reporting and thus lead to biased estimates.

In this study, we address these limitations and assess plausibly causal effects of physical activity on the risk factors for heart disease using the first National Health and Nutrition Examination Survey (NHANES I) and its follow-up study, the NHANES I Epidemiologic Follow-up Study (NHEFS). The NHANES and NHEFS constitute a population-based longitudinal survey that *objectively measures* weight, blood pressure, pulse, and a host of other behaviors and characteristics for approximately 9,300 persons. To the best of our knowledge, this is the only population-based dataset in the U.S. that provides longitudinal information on measured (as opposed to self-reported) risk factors for heart disease.

The nature of the NHANES thus enables us to make a number of contributions. First, unlike virtually all prior studies, we estimate the effects on health of both recreational exercise as well as of physical activity at work and elsewhere. The importance of disentangling the effects of recreational exercise from other physical activity stems from the likelihood that both types of activity may have differential effects on health. The importance of considering physical activity levels beyond just recreational exercise derives from the fact that for the average individual recreational exercise typically constitutes only about 3-4% of their total daily physical exertion (Colman and Dave 2011). In addition, our measure of physical activity also includes activity at work, which is often excluded in prior studies. Work-related physical activity constitutes the largest component of total physical exertion for the average individual: approximately 32% for working-aged males, and 20% for working-aged females (American Time Use Surveys-ATUS 2010). Hence, it is important to consider the totality of an individual's physical activity including their work-related activity, while separating the effects of exercise from that of other activities, which we do in this study.

Saffer et al. (2011) and Colman and Dave (2011) also show that there is considerable substitution between work-related physical activity, exercise, and other forms of recreational activity. Specifically, during an economic downturn, job loss induces individuals to increase their recreational exercise though their total physical activity level declines due to a large decrease in work-related physical activity (Colman and Dave 2011). It is difficult to assess the implications of these shifts on health without evidence on the differential effects of recreational exercise and other physical activity on health - evidence which we provide in this study.

Second, the availability of repeated observations on the same persons makes it possible to control for many of the unobserved confounding factors that affect both physical activity and health. Third, the objectivity of the measurements enables us to avoid the measurement error that has plagued prior research. Finally, NHANES I and its follow-up study generally predated the sharp rise in obesity in the U.S. and thus bypass some of the time-series confounding relating to the bi-directional link between obesity (and its adverse health consequences) and physical activity. Hence, we are able to establish baseline effects of physical activity on the risk factors for heart disease over a time period when obesity was stable, which can then be used to inform whether and to what extent physical activity can account for subsequent observed trends in these risk factors.

The rest of the manuscript is organized as follows. Section 2 describes the data used in the empirical analyses. Section 3 outlines our empirical methodology in identifying the effects of physical activity measures on health. Section 4 discusses the results, and Section 5 concludes with a discussion of the implications of our estimates.

2. Data

2.1 National Health and Nutrition Examination Survey (NHANES)

The NHANES I is a national probability sample of 31,973 persons ages 1 to 75 in the U.S., interviewed from 1971 to 1974. A random subset of 23,808 persons, the "examination sample", provided more detailed information. Examiners measured respondents' heights, weights, skinfolds (measure of body fat), and other features, and doctors examined them for signs of nutritional deficiency as well as any obvious medical problem. An additional random sample of 6,913 persons ages 24 to 75, the "augmentation sample", was interviewed in 1974 and

1975. These respondents provided virtually the same information as the examination sample, and in addition were given complete physical examinations by physicians, and answered a series of questions on general psychological well-being (GWB).

The U.S. Centers for Disease Control and Prevention (CDC) conducted a Follow-up survey to NHANES I spanning the years 1982 to 1984. The follow-up was meant to locate the 14,407 person who were part of the examination sample of NHANES I and were between 25 and 74 years old during the original survey. Ninety-three percent were either located or ascertained to have died; of these, valid responses were obtained from 91%, providing a sample of 12,220 persons. For persons who had died before the Follow-up survey, proxy responses were obtained from family members or friends. The Follow-up survey collected information on the respondents' current health or, if not still living, cause of death, income, medical history since the first survey, how often the respondent ate various foods, and also measured their weights, blood pressure, and pulse.

2.2 Measures of Risk Factors, Health, and Physical Activity

We compute the individual's body mass index (BMI) based on the conventional definition, that is weight in kilograms divided by height in meters-squared. The calculation of BMI in the first wave used the values of height and weight measured during the examination, which took place in mobile examination trailers, where subjects wore paper uniforms and rubber slippers provided by the NHANES staff.[1] Height was not measured in the Follow-up interview. Therefore, the BMI calculation in the second wave uses the respondent's measured height from the first wave on the assumption that height is stable for working-aged adults.

[1] The Follow-up survey measured respondents' weights in their usual clothing. Thus the follow-up weights were heavier by the amount of the subjects' clothing. There is no need to explicitly adjust for this since as long as the weight of the respondents' indoor clothing is approximately the same from one person to the next it will not affect correlations between weight and other variables. On average clothes weigh about 4-5 pounds, and the mean effect of clothing on weight is captured by the year fixed effects included in all models.

In addition to BMI, we use three other objectively-measured risk factors for heart disease: systolic blood pressure, diastolic blood pressure, and the resting heart rate. In NHANES I, these measurements, like height and weight, were taken in the mobile examination trailer, whereas in the follow-up they were taken largely in the respondents' homes. It is plausible that both pulse and blood pressure would be higher in a government trailer than in one's home. But as long as the difference between home and trailer measurements was about the same for each respondent, the wave/year indicator included in all models will capture this difference. Subsequently, the different circumstances of measurement will not affect the correlations between the measurements and other characteristics of the respondents.

NHANES I asks two questions on physical activity, one regarding recreational exercise and another regarding physical activity other than exercise. The question on non-recreational physical activity is the same in the first NHANES I sample (from 1971 to 1974), in the Augmentation sample (from 1974 to 1975), and in the Follow-up survey. It probes: "In your usual day, aside from recreation, are you physically very active, moderately active, or quite inactive?" We create dichotomous indicators for each response. The question on recreational exercise differed slightly between the initial survey and the Augmentation survey. In the initial survey the question reads: "Do you get much exercise in the things you do for recreation (sports, or hiking, or anything like that), or hardly any exercise, or in between?" The possible responses are: "much exercise", "moderate exercise", and "little or no exercise". The Augmentation sample questionnaire asks: "In things you do for recreation, for example: sports, hiking, dancing and so forth, do you get much exercise, moderate exercise, or little or no exercise?" We consider these questions similar enough to code the responses the same way, and create dichotomous indicators for each response.

Both surveys also ask whether the respondent had certain medical conditions. The Follow-up interview does not inquire about all the conditions queried in the original survey, and asks about additional conditions not asked in the first survey. For many of the conditions, the follow-up asks when the condition or event occurred, from which we can infer whether the respondent had the condition at the time of the first survey. We create dichotomous indicators for the conditions covered in both surveys as well as for those whose presence in the first survey can be inferred from the follow-up. These are: 1) arthritis; 2) asthma; 3) colitis; 4) diabetes; 5) emphysema; 6) gallbladder; 7) heart attack; 8) high blood pressure; 9) kidney disease; 10) nervous breakdown; 11) stroke; 12) thyroid disease; 13) ulcer; and 14) cancer.

We also create dichotomous indicators for various socio-demographic measures including different categories of marital status, gender, labor force status, and race and ethnicity. Both the original and follow-up surveys report income in categories, though the categories differ substantially to reflect the large inflation between 1971 and 1984. We create a continuous income measure by imputing to each respondent the midpoint of his or her income category, and for those whose income is in the top category, we assign the average income above the cut-off based on a Weibull distribution.[2] Education is measured by indicators for the highest grade completed.

2.3 Analysis Sample

The size of the final analysis sample depends on the outcome being studied. For purposes of illustration, we use BMI, although the calculations are virtually identical with other outcomes. Of the 12,220 participants who were traced in the Follow-up survey, 1,697 died prior to the Follow-up interview, 560 have missing values of either BMI or one of the activity variables, and

[2] We confirm that our estimates are not sensitive to alternative imputations: 1) other extreme value distributions; 2) imputing the highest income category at the top-coded value; and 3) controlling for income in the models as dichotomous indicators for the income categories.

1,274 have missing values for the other covariates. Finally, we drop 3,256 respondents over 60 years old in either wave, for two reasons. First, since height is only measured in the first wave, and declines with age, BMI is measured with increasing error for older respondents. Second, much of the variation in non-recreational physical activity reflects differences between persons working and not working, and between those in physically active occupations and other occupations. As noted earlier, among working-aged adults, about 26% of total daily physical exertion is derived from work-related activities (ATUS 2010). This variation is lost among seniors because very few of them are in the labor force.

3. Analytical Framework

The objective of this study is to assess the effect of recreational exercise and other physical activity on the risk factors for heart disease. A number of prior studies, such as those referenced above, have considered this question with longitudinal data; in fact, one prior study of one of our outcomes (BMI) also used the NHANES I and the Follow-up (Williamson et al. 1992). However, the models used in prior studies have not taken full advantage of the longitudinal nature of their data and fail to control for the many confounding factors that cause a person both to be physically active and to have risk factors for heart diseases.[3] More specifically, the two most common models estimated in prior studies are the following:

$$y_{it} = X_{it}\beta + Z_i\theta + PA_{it-1}\delta + u_{it} \tag{1}$$

and

$$y_{it} - y_{it-1} = X_{it}\beta + Z_i\theta + PA_{it-1}\delta + u_{it} \tag{2}$$

[3] In the language of the treatment effects literature, prior studies have not availed themselves of the possibilities of controlling for selection into "treatment", which in this case is "physical activity". This limits the internal validity of the estimates from this literature due to the possibility of selection bias.

where X_{it} is a vector of individual characteristics or behaviors that vary over time (such as health), Z_i is a vector of individual characteristics that do not vary over time (such as race), PA_{it}, is a measure of physical activity, and u_{it} includes all the time-varying unobserved influences on the outcome. The subscripts denote the i^{th} individual observed in time period t.

The weakness of such models is that there are almost certainly many variables in X_{it} and Z_i that affect physical activity but cannot be observed. For example, the respondent may have inherited a tendency to worry about his health or the individual may be relatively more forward-looking or risk-averse, which would cause him to watch his diet as well as to exercise. Since the inherited portion of someone's heath anxiety or their risk-aversion or future-orientation (time preference in the economics jargon) cannot be observed, it becomes part of the error term, and, being correlated with physical activity, biases the coefficients in these prior studies.

Hence we estimate a version of equation (1) that allows us to remove many of the unobserved confounding variables. Including controls for national trends (γ_t) in the outcome, our model is:

$$y_{it} = X_{it}\beta + Z_i\theta + \gamma_t + PA_{it}\delta + u_{it} \tag{3}$$

To estimate it, we take first-differences (FD) of both sides between the two NHANES waves.

$$\Delta y_{it} = \Delta X_{it}\beta + \Delta\gamma_t + \Delta PA_{it}\delta + \Delta u_{it} \tag{4}$$

Differencing removes the variables collected in Z_i, since these variables are the same in each time period. In a practical sense, we actually estimate equation (4) using the fixed-effects (FE) routine.[4] Since we have only two waves of data, FE and FD produce identical results.[5] Our key

[4] We test for the consistency of fixed versus random effects for all models based on the Hausman test, and in all cases we reject the random effects model suggesting that the Z_i are correlated with physical activity and hence the fixed effects model is preferred.

[5] One weakness of the FE (or FD) method is that it may be more vulnerable than ordinary least squares (OLS) to measurement-error bias, the bias being higher, the higher the correlation between the independent variables and their lagged values (Griliches & Hausman 1986). In our case the time between waves—about 10 years—is

parameter of interest is δ, the effect of physical activity (PA) on health-related outcomes and risk factors for heart disease. Equations (3) and (4) can be interpreted as an individual-level health production function, which relates health inputs and health investments such as physical activity and education to health outputs such as obesity, diabetes, and heart conditions (Grossman 2000).

First-differencing and FE methods solve the omitted variables problem as long as all the important omitted factors that affect selection into treatment are time-invariant. Indeed, these methods allow us to account for key unobserved time-invariant confounding factors (Angrist and Pischke 2009) such as risk preference, time preference (whether the individual is present- or future-oriented), stable personality traits, parental investments, family background, genetic/hereditary traits, and other prior health investments. But it is possible that important time-varying factors also influence both physical activity and the outcome. Among the most important such factors is the prior level of the outcome. Suppose, for example, the outcome is BMI. It is not only likely that physical activity reduces BMI contemporaneously, but also that BMI affects future physical activity. For example, a person who becomes obese may switch to a more sedentary job. Thus prior obesity affects selection into the current level of physical activity. To account for this, we also estimate the following model.

$$y_{it} = \rho y_{it-1} + X_{it}\beta + Z_i\theta + \gamma_t + PA_{it}\delta + u_{it} \tag{5}$$

Estimating (5) will produce consistent estimates of δ so long as selection into physical activity depends only on the lagged value of the outcome once we control for the other characteristics of the respondent that we can observe. One advantage to estimating both (4) and (5) is that if at least one of the models is correctly specified, and if selection into physical activity is negatively

sufficiently long that the change in physical activity is relatively large, which would tend to minimize this bias. For instance, the share of respondents who are very physically active drops by about a third from the first to the second wave, while the shares that are moderately active and that exercise with moderate intensity rise by about the same amount.

correlated with the lagged outcome (which it is, in all of the outcomes we consider), the true causal effect will lie between the two estimates (Guryan 2001; Angrist & Pischke 2009). That is, if the true model is (5) but we estimate (4), the coefficients on physical activity will be too large. On the other hand, if the true model is (4) but we estimate (5), the coefficients will be too small. More formally, we can bound the true causal effect of physical activity on health as follows, by considering the estimate of δ from equations (4) and (5).

$$\delta_{Lagged\ y} < \delta_{true} < \delta_{FE} \tag{6}$$

As a further robustness check, we can gauge whether we have uncovered causal effects by assessing outcomes that are themselves caused by the risk factors we examine. For examine, if an increase in physical activity reduces blood pressure, and if a decrease in blood pressure reduces heart disease, we should find that heart disease is negatively related to physical activity as well. Therefore we also estimate the effect of physical activity on other heart- and obesity-related outcomes that are available for both waves of the NHANES, including self-reported diabetes, high blood pressure, angina, and heart trouble.

4. Results

As evident from the means reported in Table 1, the persons sampled in the NHANES I became substantially less active in general during the ten years that on average separated their two interviews. The proportion of respondents reporting they that were very active outside of recreational exercise fell by about 37% among non-Hispanic whites (from 48.8% to 30.7%), and by about 30% for the other racial and ethnic categories. Similarly, the prevalence of a high level of recreational exercise also declined among non-Hispanic whites (by about 20%) but increased among the other racial and ethnic groups.

It is difficult to discern from the means the trends in the objectively-measured risk factors, partly because, as mentioned above, the circumstances of measurement may have differed between the NHANES I and the Follow-up interviews. This is especially noticeable in the average pulse rate, which appears to have declined by 10 beats per minute between the two surveys. This likely reflects differences in the circumstances of measurement since, as far as we know, no medication to slow the pulse rate spread rapidly between the early 1970s and the early 1980s. Medication may, however, explain the decline in average blood pressure over this period (Kumanyika et al. 1998). As a further check, we also analyze self-reported hypertension. As shown in the Table 1, including those whose measured blood pressure is high as well as those who take medicine to reduce their blood pressure, the proportion with high blood pressure approximately doubled across all racial and ethnic groups. These unconditional means suggest that the decline in physical activity between the two waves coincided with a worsening of the risk factors for heart disease. However, due to possible confounding with national trends, with the aging of the sample, and with other factors, we cannot infer causal effects from a comparison of means. We therefore turn to the multivariate regression results. For all regression models, the reported standard errors are adjusted for arbitrary correlation in the error term over time for each individual.

Table 2 presents models for body mass index (BMI). Specification 1 estimates an OLS model relating lagged activity measures to BMI. Specification 2 estimates the first-differenced (identical to fixed effects) model specified in equation (4), and the final specification estimates the model with the lagged dependent variable specified in equation (5). Several patterns stand out in these models. First, the lagged effect of physical activity is almost always larger than the current effect. For instance, individuals who were very active (excluding recreational exercise) *in* *the previous wave* had a lower BMI by about 1.07 points in the follow-up wave, relative to individuals who were inactive. In contrast, contemporaneous levels of high activity (excluding recreational exercise) also reduced BMI, but by a smaller margin (0.42 points in model 2 and 0.31 points in model 3). That is, while current physical activity levels have a protective effect towards reducing the risk factors for heart disease, the estimates suggest that there are strong lagged and durable effects of physical activity. This may indicate that current risk factors, not only obesity but also high blood pressure and heart rate, take years to develop, which emphasizes the importance of consistent physical activity to ward off heart disease.

Second, almost all results for all outcomes conform to equation (6): in general, controlling for the lagged dependent variable suggests a larger effect than controlling for fixed effects. This implies that the true effect is between the coefficients in columns 2 and 3 of each table, implying that in general physical activity reduces risk factors for heart disease even after controlling, to some extent, for unobservable influences. Thus, with respect to BMI, high-levels of physical activity (excluding recreational exercise) reduce BMI by between 0.31 to 0.42 points (relative to inactivity) and high levels of recreational exercise reduce BMI by between 0.28 to 0.78 points (relative to little or no exercise).

Third, not only recreational but other physical activity (most of which is work-related) appears to also protect against heart disease. We cannot reject the null hypothesis that the magnitudes of the protective effect for both types of activities (recreational exercise versus other/work-related physical activity) are the same.[6] Colman and Dave (2011) show that individuals who lose their jobs during an economic recession raise their exercise levels due to a

[6] However, this is not to say that the effects of work-related or other physical activity are necessarily uniform across all individuals. It is possible that work-related physical activity may have muted effects on health, or even adverse effects, for individuals in certain physically-demanding occupations that have very high sustained energy demands. For a discussion, see Kukkonen-Harjula (2007).

greater availability of time, though their total physical exertion declines due to a larger drop in work-related physical activity. Our estimates imply that this net decline in physical activity during an economic downturn would have a net adverse effect on individuals' risk factors for heart disease.

Fourth, the models indicate suggestive evidence of a dose-response relationship. In general, the protective effects of high levels of recreational exercise and other activity are stronger than the protective effects of moderate levels, relative to the effects of no exercise or the effects of inactivity.[7]

Tables 3 and 4 present models respectively for measured systolic and diastolic blood pressure, and Table 5 presents models for the measured pulse rate. While most of these effects are imprecisely estimated with large standard errors, the patterns remain robust. In general, physical activity measures (especially other physical activity besides recreational exercise, most of which is comprised of work-related activities) has a strong durable protective effect in reducing blood pressure and reducing the resting heart rate. A number of studies indicate that a faster resting heart rate is a risk factor for cardiovascular mortality (see for instance, Kannel et al. 1987). Again, we find protective effects for both recreational exercise and other work-related physical activity, at least with respect to blood pressure. With respect to the pulse rate, estimates suggest that a high level of other work-related physical activity has a lagged durable effect (reducing the pulse rate by about 1 beat per minute) though no discernible contemporaneous effect. A high level of recreational exercise, on the other hand, has both strong contemporaneous

[7] The effects of the other included covariates (not reported) on risk factors for heart disease and the other health conditions are consistent with the literature. In general, educated individuals tend to be healthier, which is consistent with Grossman and Kaestner (1997) who suggest that educated individuals tend to be more efficient in "producing" health and engage in more (less) healthy (risky) behaviors. Higher levels of income also generally have a protective effect on health. Risk factors for heart disease and health tend to worsen over the life cycle. The effects of marital status and race/ethnicity vary depending on the risk factor and morbidity in question. Full results are available upon request.

effects (reducing the resting pulse rate by between 1.1 to 2.6 beats per minute) as well as a strong lagged effect (reducing the pulse rate by about 1.2 beats per minute).

Table 6 specifically considers the incidence of hypertension. Across all models, all coefficient estimates are negative implying that both forms of physical activity reduce the prevalence of high blood pressure contemporaneously as well as in the long term. We estimate that a high level of recreational exercise reduces the probability of having high blood pressure by between 2.8 and 8.4 percentage points, which represents a 10-31% reduction in the prevalence relative to the mean in the Follow-up interviews. A high level of other physical activity reduces the likelihood of hypertension by between 2.3 to 4.3 percentage points (about a 9-16% reduction relative to the mean).

Given that both recreational exercise and other physical activity reduces the risk factors associated with heart disease (BMI, high blood pressure, and a high resting heart rate), we would expect favorable effects on heart-related morbidities. Thus, Tables 7-9 present a plausibility check by assessing effects on outcomes that are themselves caused by these risk factors. Specifically, we consider diabetes (Table 7), angina (Table 8), and heart disease (Table 9). In general, these estimates suggest that physical activity measures are associated with a reduced prevalence of each of these heart- and obesity-related morbidities. For instance, a high level of recreational exercise and other physical activity reduces the probability of diabetes by as much as 2 percentage points (Model 3 in Table 7) and the probability of heart disease by as much as 2-4 percentage points (Model 3 in Table 9). These results are validating in that they confirm the causal chain from physical activity to a reduction in risk factors for heart disease to ultimately a reduction in heart-related and obesity-related disease conditions.

It may be that estimating a causal effect requires controlling for time-varying factors that may influence both the outcome and physical activity. We include a number of such factors, such as the respondent's age, marital status, state or region of residence, and month of interview to account for seasonality in all reported models. From the NHANES questionnaire, we can also construct a great many indicators for health conditions. Some of these conditions, or the lack of them, may be caused by physical activity, such as heart disease, stroke, high blood pressure, angina, cancer, and a number of other morbidities. Since these conditions affect the outcomes we study, it might seem reasonable to include them as covariates. But doing so would bias the coefficients on physical activity because in part these conditions also result from physical activity (Rosenbaum 1984). Therefore, in supplementary analyses (not reported but available upon request), we include indicators for a number of conditions that may affect the outcomes under study -- but do not, as far as we can determine, result from physical activity -- conditions such as epilepsy, detached retina, glaucoma, cataracts, diverticulitis, Parkinson's, cirrhosis, psoriasis, migraines, kidney disease, and emphysema. The estimates from these extended models are virtually the same as those reported in Tables 2-9. This robustness is further validating and adds a degree of confidence to our causal bounds of the effects of activity measures on risk factors and morbidities.

5. Summary & Discussion

While the link between physical activity and health has been studied in the past, there are several limitations that persist in the literature. Estimates from randomized controlled studies are often based on small, convenience samples and difficult to generalize to the population-level, while observational population-based studies often fail to account for the various confounding factors that drive both physical activity and health. Furthermore, many of the prior studies have either only considered recreational exercise, which provides an incomplete picture since such exercise typically constitutes only about 3-4% of an individual's total physical exertion, or failed to separately consider other forms of physical activity, especially activity levels that include work-related physical activity. This latter point is significant since work-related physical activity is the single largest component of total physical exertion for working aged adults, and work-related physical activity and recreational exercise often move opposite to each other over the business cycle. That is, as individuals increase their labor supply during periods of high employment, they tend to reduce their recreational exercise on average. Hence, it is important to consider both of these forms of activities separately when assessing their effects on health markers. Finally, much of the prior work has relied on self-reported measures of weight and height, and risk factors such as blood pressure, which may be subject to measurement error.

In this study, we addressed these limitations and assessed the plausibly causal effects of recreational exercise and other physical activity, including work-related physical activity, on the risk factors for heart disease using a longitudinal population-based dataset with objectively measured risk factors. Fixed-effects models control for all time-invariant observed and unobserved confounding factors. In addition, comparing these estimates with those derived from models with a lagged dependent variable allows us to bound the causal effect under reasonable assumptions (Angrist & Pischke 2009).

We find robust evidence that both recreational exercise and other physical activity have a similar protective effect on health by reducing the risk factors (BMI, high blood pressure, and resting heart rate) associated with heart disease. In supplementary models, we also find positive effects on actual health outcomes, including a reduction in diabetes, angina, and heart disease.

There is also some suggestive evidence that physical activity has durable effects on health, emphasizing the importance of engaging in a consistently active lifestyle over time.

Table 1 documented the reduced prevalence in high levels of exercise and other physical activity between the two waves of the NHANES. Given the health-promoting effects of recreational exercise and other forms of physical activity, these declining trends in activity levels have adverse implications for population health. Brownson, Boehmer, and Luke (2005) report longer-term trends (up to 50 years for certain measures) in physical activity in the U.S. They also conclude that there is an overall trend of declining total physical activity due to a decrease in work-related physical activity, declining transportation activity, declining home-based activity, and increased sedentary activity. Church et al. (2011) document a decrease in daily occupation-related energy expenditure by more than 100 calories between 1960–62 and 2003–06, based on the NHANES, suggesting a declining trend in work-related physical activity levels.

The results from this study suggest that the reduced levels of physical activity will lead to adverse consequences on weight-based health and heart-related morbidity by increasing the incidence of obesity, high blood pressure, and the resting heart rate, ceteris paribus. Based on the midpoint of the bounded effects (Models 2 and 3 for each outcome), our *contemporaneous* estimates indicate that the reduced levels of high recreational exercise and other physical activity (and shifts in other activity measures) can explain about 3-10% of the increase in BMI and hypertension, and consequently about 2-8% of the increase in diabetes and heart disease, between the two waves of the NHANES. We note that since physical activity has a strong durable effect on risk factors and morbidities, these explained effects are understated.[8] Further accounting for the durable effects (Model 1 for each outcome), the reduced high levels of

[8] Our durable effects are estimated over a 10 year period on average. To the extent that physical activity has a cumulative effect that persists beyond this period, the observed declines in high levels of exercise and physical activity can lead to further worsening of the risk factors and an increase in weight- and heart-related morbidities.

exercise and physical activity observed over the sample period can account for an additional 10-20% of the increase in the noted risk factors and illness conditions.

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Table 1
Sample Means by Race & Ethnicity
NHANES I (1971-1975) and NEFS (1982-1984)

Variable	***Full analysis sample***		***Non-Hispanic white***		***Hispanic origin***		***Non-Hispanic black***	
	1971 - 1975	***1982 - 1984***	***1971 - 1975***	***1982 - 1984***	***1971 - 1975***	***1982 - 1984***	***1971 - 1975***	***1982 - 1984***
Body mass index	25.1	26.5	24.9	26.1	26.4	27.9	26.7	28.4
Systolic blood pressure	123.5	122.8	123.0	122.0	121.0	123.8	128.4	129.0
Diastolic blood pressure	80.7	77.7	80.4	77.3	77.6	77.4	84.3	81.1
Pulse, beats per minute	80.6	71.1	80.8	70.9	78.5	70.0	79.8	72.6
Diabetes (%)	1.7	4.6	1.6	3.7	2.9	9.1	2.0	9.3
High blood pressure (%)	13.2	27.3	12.0	24.7	12.9	31.1	22.7	45.5
Angina (%)	0.6	2.3	0.7	2.4	0.0	1.4	0.5	2.3
Heart trouble (%)	3.6	8.4	3.9	8.5	1.0	4.8	2.3	9.6
Very active (non-recreation) (%)	49.1	31.2	48.8	30.7	47.4	33.5	52.0	35.6
Moderately active (non-recreation) (%)	43.4	54.8	43.9	55.3	39.7	51.7	40.6	51.5
High level of recreational exercise (%)	20.6	18.0	22.2	17.8	8.6	17.2	13.2	19.2
Moderate recreational exercise (%)	40.8	52.3	42.5	54.0	36.4	42.6	29.8	43.5
Age at interview	36.4	46.4	36.5	46.4	35.5	46.0	36.4	46.7
Household size	4.2	3.5	4.1	3.4	4.7	3.9	4.8	3.9
Divorced (%)	5.4	12.8	4.8	11.2	5.3	17.7	10.4	24.0
Widowed (%)	2.0	4.3	1.8	3.5	2.9	8.6	3.6	8.3
Never married (%)	6.9	4.7	6.0	4.0	4.8	3.3	13.7	10.3
Real family income in $1000s	28.2	29.6	29.6	31.4	20.3	21.2	19.7	19.0
Female (%)	64.7	64.7	63.9	63.9	62.2	62.2	72.0	72.0
Less than high-school (%)	27.3	27.3	23.3	23.3	60.1	60.1	47.2	47.2
High-school (%)	42.5	42.5	44.5	44.5	24.1	24.1	35.3	35.3
Some college (%)	14.9	14.9	15.4	15.4	10.8	10.8	11.5	11.5
College graduate (%)	8.1	8.1	9.0	9.0	3.0	3.0	3.2	3.2
Post-college (%)	6.9	6.9	7.5	7.5	2.0	2.0	2.7	2.7
Observations	5433	5433	4555	4555	209	209	604	604

Table 2
Dependent Variable: Body Mass Index (BMI)

Model Specification	(1) Lagged Activity	(2) Fixed Effects	(3) Lagged Outcome
Very active excl. recreational exercise, lagged	-1.067***	_	_
	(0.315)		
Moderately active excl. recreational exercise, lagged	-0.691*	_	_
	(0.317)		
High level of recreational exercise, lagged	-1.022***	_	_
	(0.193)		
Moderate level of recreational exercise, lagged	-1.118***	_	_
	(0.163)		
Very active excluding recreational exercise	_	-0.419***	-0.311*
		(0.114)	(0.131)
Moderately active excluding recreational exercise	_	-0.175	-0.196
		(0.106)	(0.126)
High level of recreational exercise	_	-0.277**	-0.777***
		(0.090)	(0.110)
Moderate level of recreational exercise	_	0.001	-0.273**
		(0.069)	(0.092)
R-squared	0.046	0.218	0.732
Observations	5438	10873	5435

Notes: Panel-robust standard errors are reported in parentheses. Fixed-effects models control for year and month of interview, age at interview, household size, marital status (divorced, widowed, never married), and family income. Other models additionally control for race and ethnicity (Hispanic, non-Hispanic Black, non-Hispanic other), education (High school, some college, college, and post-graduate), and gender. Asterisks denote statistical significance as follows: * $p<0.05$, ** $p<0.01$, *** $p<0.001$.

Table 3
Dependent Variable: Systolic Blood Pressure

Model Specification	(1) Lagged Activity	(2) Fixed Effects	(3) Lagged Outcome
Very active excl. recreational exercise, lagged	-0.622	_	_
	(0.847)		
Moderately active excl. recreational exercise, lagged	0.137	_	_
	(0.850)		
High level of recreational exercise, lagged	-0.019	_	_
	(0.589)		
Moderate level of recreational exercise, lagged	-0.876	_	_
	(0.472)		
Very active excluding recreational exercise	_	-0.147	-0.215
		(0.660)	(0.633)
Moderately active excluding recreational exercise	_	0.399	-0.194
		(0.623)	(0.583)
High level of recreational exercise	_	-0.079	-0.435
		(0.541)	(0.584)
Moderate level of recreational exercise	_	-0.199	-0.289
		(0.417)	(0.446)
R-squared	0.167	0.039	0.319
Observations	5362	10778	5341

Notes: Panel-robust standard errors are reported in parentheses. Fixed-effects models control for year and month of interview, age at interview, household size, marital status (divorced, widowed, never married), and family income. Other models additionally control for race and ethnicity (Hispanic, non-Hispanic Black, non-Hispanic other), education (High school, some college, college, and post-graduate), and gender. Asterisks denote statistical significance as follows: * $p<0.05$, ** $p<0.01$, *** $p<0.001$.

Table 4
Dependent Variable: Diastolic Blood Pressure

Model Specification	(1) Lagged Activity	(2) Fixed Effects	(3) Lagged Outcome
Very active excl. recreational exercise, lagged	-0.947	_	_
	(0.541)		
Moderately active excl. recreational exercise, lagged	-0.327	_	_
	(0.545)		
High level of recreational exercise, lagged	-0.042	_	_
	(0.387)		
Moderate level of recreational exercise, lagged	-0.416	_	_
	(0.302)		
Very active excluding recreational exercise	_	0.026	-0.035
		(0.458)	(0.415)
Moderately active excluding recreational exercise	_	0.012	-0.153
		(0.420)	(0.384)
High level of recreational exercise	_	-0.066	-0.345
		(0.377)	(0.391)
Moderate level of recreational exercise	_	-0.269	-0.075
		(0.282)	(0.289)
R-squared	0.091	0.108	0.246
Observations	5362	10779	5342

Notes: Panel-robust standard errors are reported in parentheses. Fixed-effects models control for year and month of interview, age at interview, household size, marital status (divorced, widowed, never married), and family income. Other models additionally control for race and ethnicity (Hispanic, non-Hispanic Black, non-Hispanic other), education (High school, some college, college, and post-graduate), and gender. Asterisks denote statistical significance as follows: * $p<0.05$, ** $p<0.01$, *** $p<0.001$.

Table 5
Dependent Variable: Pulse, beats per minute

Model Specification	(1) Lagged Activity	(2) Fixed Effects	(3) Lagged Outcome
Very active excl. recreational exercise, lagged	-1.043	_	_
	(0.566)		
Moderately active excl. recreational exercise, lagged	-0.838	_	_
	(0.565)		
High level of recreational exercise, lagged	-1.238**	_	_
	(0.407)		
Moderate level of recreational exercise, lagged	-0.397	_	_
	(0.320)		
Very active excluding recreational exercise	_	0.170	0.170
		(0.524)	(0.452)
Moderately active excluding recreational exercise	_	0.143	-0.096
		(0.478)	(0.415)
High level of recreational exercise	_	-1.095*	-2.618***
		(0.458)	(0.414)
Moderate level of recreational exercise	_	-0.676*	-1.221***
		(0.341)	(0.317)
R-squared	0.017	0.339	0.111
Observations	5426	10841	5403

Notes: Panel-robust standard errors are reported in parentheses. Fixed-effects models control for year and month of interview, age at interview, household size, marital status (divorced, widowed, never married), and family income. Other models additionally control for race and ethnicity (Hispanic, non-Hispanic Black, non-Hispanic other), education (High school, some college, college, and post-graduate), and gender. Asterisks denote statistical significance as follows: * $p<0.05$, ** $p<0.01$, *** $p<0.001$.

Table 6
Dependent Variable: Has High Blood Pressure

Model Specification	(1) Lagged Activity	(2) Fixed Effects	(3) Lagged Outcome
Very active excl. recreational exercise, lagged	-0.056* (0.025)	_	_
Moderately active excl. recreational exercise, lagged	-0.027 (0.025)	_	_
High level of recreational exercise, lagged	-0.051** (0.017)	_	_
Moderate level of recreational exercise, lagged	-0.063*** (0.014)	_	_
Very active excluding recreational exercise	_	-0.023 (0.017)	-0.043* (0.019)
Moderately active excluding recreational exercise	_	-0.018 (0.016)	-0.030 (0.017)
High level of recreational exercise	_	-0.028* (0.014)	-0.084*** (0.017)
Moderate level of recreational exercise	_	-0.001 (0.011)	-0.051*** (0.013)
R-squared	0.065	0.122	0.221
Observations	5438	10873	5435

Notes: Panel-robust standard errors are reported in parentheses. Fixed-effects models control for year and month of interview, age at interview, household size, marital status (divorced, widowed, never married), and family income. Other models additionally control for race and ethnicity (Hispanic, non-Hispanic Black, non-Hispanic other), education (High school, some college, college, and post-graduate), and gender. Asterisks denote statistical significance as follows: * $p<0.05$, ** $p<0.01$, *** $p<0.001$.

Table 7
Dependent Variable: Has Diabetes

Model Specification	(1) Lagged Activity	(2) Fixed Effects	(3) Lagged Outcome
Very active excl. recreational exercise, lagged	-0.020	_	_
	(0.013)		
Moderately active excl. recreational exercise, lagged	-0.006	_	_
	(0.013)		
High level of recreational exercise, lagged	-0.010	_	_
	(0.008)		
Moderate level of recreational exercise, lagged	-0.013	_	_
	(0.007)		
Very active excluding recreational exercise	_	-0.009	-0.021*
		(0.008)	(0.010)
Moderately active excluding recreational exercise	_	-0.013	-0.011
		(0.007)	(0.009)
High level of recreational exercise	_	-0.000	-0.022**
		(0.007)	(0.008)
Moderate level of recreational exercise	_	0.002	-0.018**
		(0.005)	(0.007)
R-squared	0.024	0.037	0.168
Observations	5438	10873	5435

Notes: Panel-robust standard errors are reported in parentheses. Fixed-effects models control for year and month of interview, age at interview, household size, marital status (divorced, widowed, never married), and family income. Other models additionally control for race and ethnicity (Hispanic, non-Hispanic Black, non-Hispanic other), education (High school, some college, college, and post-graduate), and gender. Asterisks denote statistical significance as follows: * $p<0.05$, ** $p<0.01$, *** $p<0.001$.

Table 8
Dependent Variable: Has Angina

Model Specification	(1) Lagged Activity	(2) Fixed Effects	(3) Lagged Outcome
Very active excl. recreational exercise, lagged	-0.021*	_	_
	(0.011)		
Moderately active excl. recreational exercise, lagged	-0.024*	_	_
	(0.011)		
High level of recreational exercise, lagged	-0.007	_	_
	(0.005)		
Moderate level of recreational exercise, lagged	-0.009*	_	_
	(0.005)		
Very active excluding recreational exercise	_	-0.007	-0.014
		(0.006)	(0.007)
Moderately active excluding recreational exercise	_	-0.002	-0.011
		(0.006)	(0.007)
High level of recreational exercise	_	-0.009*	-0.015**
		(0.004)	(0.005)
Moderate level of recreational exercise	_	-0.006	-0.013**
		(0.003)	(0.005)
R-squared	0.028	0.040	0.286
Observations	5435	10867	5432

Notes: Panel-robust standard errors are reported in parentheses. Fixed-effects models control for year and month of interview, age at interview, household size, marital status (divorced, widowed, never married), and family income. Other models additionally control for race and ethnicity (Hispanic, non-Hispanic Black, non-Hispanic other), education (High school, some college, college, and post-graduate), and gender. Asterisks denote statistical significance as follows: * $p<0.05$, ** $p<0.01$, *** $p<0.001$.

Table 9
Dependent Variable: Has Heart Trouble

Model Specification	(1) Lagged Activity	(2) Fixed Effects	(3) Lagged Outcome
Very active excl. recreational exercise, lagged	-0.027	_	_
	(0.017)		
Moderately active excl. recreational exercise, lagged	-0.018	_	_
	(0.017)		
High level of recreational exercise, lagged	-0.012	_	_
	(0.011)		
Moderate level of recreational exercise, lagged	-0.018*	_	_
	(0.009)		
Very active excluding recreational exercise		-0.030**	-0.043***
		(0.010)	(0.011)
Moderately active excluding recreational exercise		-0.022*	-0.026*
		(0.009)	(0.011)
High level of recreational exercise		-0.009	-0.024**
		(0.007)	(0.009)
Moderate level of recreational exercise		-0.001	-0.019*
		(0.006)	(0.007)
R-squared	0.025	0.073	0.422
Observations	5437	10871	5434

Notes: Panel-robust standard errors are reported in parentheses. Fixed-effects models control for year and month of interview, age at interview, household size, marital status (divorced, widowed, never married), and family income. Other models additionally control for race and ethnicity (Hispanic, non-Hispanic Black, non-Hispanic other), education (High school, some college, college, and post-graduate), and gender. Asterisks denote statistical significance as follows: * $p<0.05$, ** $p<0.01$, *** $p<0.001$.