***Journal of Physical Activity and Health*, (Ahead of Print)**
https://doi.org/10.1123/jpah.2018-0423

Human Kinetics
ORIGINAL RESEARCH

Is Active Transport and Leisure-Time Physical Activity Associated With Inflammatory Markers in US Adults? A Cross-Sectional Analyses From NHANES

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Background: To investigate the association between levels of active transport and leisure-time physical activity (LTPA) with C-reactive protein, white blood cell count, body mass index, waist circumference, and lipids in a large representative sample of adults residing in the United States. **Methods**: Cross-sectional data from the National Health and Nutrition Examination Survey. Adjusted multinomial logistic regressions were carried out to quantify associations between levels of self-reported active transport (or LTPA) and quintiles of anthropometric measures and serum markers. **Results**: A total of 3248 adults were included. For serum inflammatory biomarkers, the authors observed a lower likelihood of being in the top quintile groups of circulating C-reactive protein (adjusted odds ratio [aOR]: 0.60; 95% confidence interval [CI], 0.40–0.90) and white blood cell count (aOR: 0.65; 95% CI, 0.44–0.95) with engaging in low to medium levels of active transport but not with high levels of active transport. Higher levels of LTPA were associated with lower likelihood of having high levels of serum inflammatory biomarkers (aOR: 0.60; 95% CI, 0.42–0.86 in the top C-reactive protein group and aOR: 0.58; 95% CI, 0.39–0.87 in top white blood cell group). **Conclusions**: Promoting active transport and/or LTPA may be a beneficial strategy to improving some, but not all, cardiometabolic health outcomes.

Keywords: walking, cycling, anthropometric

Regular and sustained participation in physical activity aids in the prevention of noncommunicable diseases and associated risk factors.[1,2] Adults can achieve adequate levels of physical activity (30 min/d on 5 d/wk at least moderate intensity) through a variety of domains. Two key domains include leisure-time physical activity (LTPA) and active travel (ie, walking and cycling). Although there is sufficient evidence to show that overall physical activity is beneficial for physical health,[1,2] domain-specific benefits are known to a lesser extent.

Overall physical activity may have beneficial anti-inflammatory effects; evidence from epidemiological studies has consistently demonstrated an inverse association between physical activity and markers of low-grade systemic inflammation.[3–5] The anti-inflammatory effects of exercise may partly explain the well-documented cardioprotective effects of physical activity.[6–8] An important and well-studied inflammatory marker is C-reactive protein (CRP), a protein found in blood plasma. The level of CRP, which can be measured in your blood, increases when there is inflammation in your body. Importantly, CRP has been shown to be inversely associated with physical activity[9] and it has been shown to predict, independently of conventional risk factors, coronary heart disease and cardiovascular disease mortality in the general population and also in patients with type 2 diabetes.[10,11] Another important and often-studied inflammatory marker is total white blood cell (WBC) count. A low WBC count (leukopenia) is a decrease in disease-fighting cells (leukocytes) in the blood. WBC count has been shown to have an inverse association with overall physical activity and to be independently associated with noncommunicable diseases, such as coronary heart disease (eg, see Twig et al[12]).

A recent systematic review[13] on the associations between active transport and health (including a total of 24 studies from 12 countries, 15 of which included adult samples) concluded that active transport may have positive effects on health outcomes. However, the review identified just one study investigating the association between active transport and lipid levels and showing an increase in high-density lipoprotein cholesterol (HDL-C) but no changes in serum total cholesterol or triglyceride concentrations.[14] Further research is required to confirm or refute these findings. Another systematic review investigated the association between active transport and adiposity in adults and concluded that there is limited evidence that active transport is associated with more physical activity and lower body weight.[15] However, study heterogeneity and crude measures for active transport and physical activity impede quantitative conclusions.[15] Interestingly, to our knowledge, few studies have investigated associations between

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active transport and inflammatory markers—CRP and WBC count. With regard to associations between LTPA and health, one systematic review[16] was identified that explored associations between LTPA and incident metabolic syndrome. This review included 16 articles and found that any amount of LTPA is better than none and that LTPA substantially exceeding the current physical activity guidelines is associated with an additional reduction in metabolic syndrome risk.[16] However, few studies have investigated such associations of LTPA with inflammatory biomarkers—WBC count and CRP.

Considering the current gaps in the literature, the present study asked the question: what are the relationships between active transport and levels of LTPA with inflammatory markers in US adults? The aim of the present study was to investigate the association between levels of active transport and LTPA with CRP, WBC count, body mass index (BMI), waist circumference, and lipids in a large representative sample of adults residing in the United States. We hypothesized that lower levels of active travel or LTPA would be associated with unfavorable cardiometabolic risk factor outcomes.

Methods

Study Population

Cross-sectional analyses using data from the National Health and Nutrition Examination Survey (NHANES) were carried out. The NHANES was designed to provide cross-sectional estimates on the prevalence of health, nutrition, and potential risk factors among the civilian noninstitutionalized US population up to 85 years of age.[17] In brief, the NHANES surveys a nationally representative, complex, stratified, multistage, probability-clustered sample of about 5000 participants each year in 15 counties across the country. Survey participants were asked to attend a physical examination in a mobile examination center or in the participants' home. The NHANES obtained ethical approval from the National Centre for Health Statistics Research Ethics Review Board, and participants provided written informed consent.

We extracted demographic information, employment status, measures of adiposity, drinking and smoking history, self-reported LTPA, self-reported walking and cycling for travel, and inflammatory and lipid biomarkers and combined them into a single data set for each data collection wave. We created a single data set for each wave of data from NHANES 2007–2008 and 2009–2010 and excluded those who were younger than 20 years old, were pregnant, or were unable to walk for a quarter mile.

Active Transport

Participants self-reported their active transport behavior in the 2007–2008 and 2009–2010 waves. Participants were asked if they walk or use a bicycle for at least 10 minutes continuously to get to and from places (to work, for shopping, to school). Participants who answered "no" to this question were classified as nonactive transporters (0 min/wk active transport). Those who answered "yes" were asked about activity frequency ("In a typical week, on who many days do you walk or bicycle for at least 10 minutes continuously to get to and from places?") and duration ("How much time do you spend walking or bicycling for travel on a typical day?"). Levels of active transport were calculated as the weekly minutes that participants reported participating in walking or cycling by multiplying the number of days participants walked or bicycled by their daily duration. Travel mode was defined as nonactive transport (0 min/wk active transport),[18] low level of active transport (<150 min/wk), and high level of active transport (≥150 min/wk).

Anthropometry

Weight and height were measured at the time of physical examinations at the mobile examination center. The measurements followed standard procedures and were carried out by trained technicians using standardized equipment. BMI was calculated as weight in kilograms/height in meters squared. We categorized study participants into standard BMI categories: underweight (<18.5 kg/m^2), normal weight (18.5–24.9 kg/m^2), overweight (25.0–29.9 kg/m^2), and obese (≥30.0 kg/m^2). For analytic purposes, we combined underweight and normal weight participants (≤25 kg/m^2).[19] Waist circumference was measured according to World Health Organization procedures in centimeters.

Serum Inflammatory Biomarkers and Lipid Markers

The process of blood collection is detailed in the NHANES Laboratory/Medical Technologist Procedures Manual.[20] Circulating CRP was quantified by latex-enhanced nephelometry with a Behring Nephelometer Analyzer System (Dade Behring Diagnostic, Inc, Newark, DE). CRP levels were categorized as low (<1.0 mg/L), moderate (1.0–3.0 mg/L), or high (>3.0 mg/L).[21] Individuals with CRP levels ≥10 mg/L were excluded, because such levels may represent an acute infective episode. WBCs were counted with Coulter HMX Hematology Analyzer (Beckman Coulter, CA), a quantitative, automated hematology analyzer and leukocyte differential cell counter for in vitro diagnostic use in clinical laboratories. Serum HDL-C, total cholesterol, and triglycerides were determined enzymatically on a Roche Modular P chemistry analyzer (Roche Diagnostics, Indianapolis, IN). Low-density lipoprotein cholesterol was calculated using the Friedewald formula: total cholesterol − (HDL-C) − (triglycerides/5), which restricted the sample to triglyceride values less than or equal to 400 mg/dL for validity.[22]

Sociodemographic Characteristics

Sociodemographic characteristics, including age, gender, race and ethnicity, education, marital status, smoking and drinking behavior, ratio of family income to poverty, employment status, and chronic illness, were extracted. Based on self-reported race and ethnicity, participants were classified into 1 of 3 racial/ethnic groups: non-Hispanic white, non-Hispanic black, and Hispanic and others. Education levels were classified into 4 groups: less than 12th grade, high school, some college, and college graduate or above. Participants' marital status was summarized into 2 groups: live with someone (married and living with partner) and live alone (widowed, divorced, separated, never married). Based on self-reported occupation, we created a binary variable for employed (working at a job or business, with a job or business but not at work) and unemployed (looking for work, not working at a job or business). Ratio of family income to poverty, which was used as an indicator of socioeconomic status, was categorized into 6 groups (<1, 1–1.9, 2–2.9, 3–3.9, 4–4.9, 5, and above). Alcohol consumption was classified into 3 categories: never drink, one drink per week, and more than one drink per week. Finally, we classified participants into 3 groups: never smokers (did not smoke 100 cigarettes and do not smoke now), former smokers (smoked 100 cigarettes in life and do not smoke now), and current smokers (smoked 100 cigarettes in life and smoke now).

Self-Reported LTPA

Participants self-reported their daily activities and leisure-time activities using questions based on the Global Physical Activity Questionnaire.[23] Levels of LTPA were calculated as the minutes per week that participants reported participating in moderate- to vigorous-intensity physical activity (MVPA). Participants reported the number of days and minutes spent in moderate and vigorous recreational activities in a typical week by answering the questions "In a typical week, on how many days do you do vigorous-intensity sports, fitness, or recreational activities?," "Minutes vigorous recreational activities," "In a typical week, on how many days do you do moderate-intensity sports, fitness, or recreational activities?," and "Minutes moderate recreational activities." We summarized the total number of minutes for both activities by doubling the number of minutes spent in vigorous-intensity physical activity and adding the total to the number of minutes of moderate-intensity physical activity to reach a value approximately equivalent the metabolic equivalent value.[24] Participants were classified as inactive (0 min/wk MVPA), insufficiently active (<150 min/wk MVPA), and sufficiently active (≥150 min/wk MVPA) based on the World Health Organization physical activity guidelines.[25]

Statistical Analysis

Survey analysis procedures were used to account for the sample weights (mobile examination center exam weight), stratification, and clustering of the complex sampling design to ensure nationally representative estimates. We included participants with completed information on active transport behavior, sociodemographic characteristics, self-reported LTPA, anthropometric measures, and serum markers. A total of 3248 adults provided sufficient data for analyses. We calculated the descriptive statistics for participants' characteristics, LTPA categories, anthropometric measures, and serum markers by their active transport status. We summarized weighted means and SEs for continuous variables, and weighted proportions for categorical variables.

Multinomial logistic regressions were carried out to quantify associations between levels of self-reported active transport (or LTPA) and quintiles of anthropometric measures and serum markers. The multivariable models were adjusted for age, gender, race and ethnicity, education level, marital status, smoking and drinking status, ratio of family income to poverty, employment status, chronic illnesses, and self-reported LTPA (or active transport) for anthropometric measures, and additionally adjusted for BMI for serum inflammatory and lipid markers. Results from the logistic regression models are presented as odds ratios (ORs) with 95% confidence intervals (95% CIs). Further sensitivity analyses were carried out using multivariable linear regression, treating anthropometric measures and serum markers as continuous variables. All statistical significance was set at $P < .05$. All statistical analyses were performed using Stata version 14.0 (STATA Corp, College Station, TX).

Results

A total of 3248 adults aged 20 years or older (mean age 46 y [SE = 0.45]) had sufficient data on travel behavior, LTPA, anthropometric measures, serum inflammatory biomarkers and lipid markers, and covariates. We excluded participants who were pregnant or indicated physical function limitations by reporting "unable to do" in response to the question "walking for a quarter mile difficulty." Our study population consisted of 3139 adults with completed data. The majority of the study population did not engage in active transport (74.7%). We observed statistically significant differences between nonactive and active travelers for most characteristics except for smoking behavior, employment status, serum LDL cholesterol, total cholesterol, and triglyceride levels (Table 1).

Associations of Active Transport With Anthropometric Measures, Serum Inflammatory Biomarkers, and Lipid Markers

Tables 2–4 summarize both the adjusted association of levels of active transport and LTPA with anthropometric measures, serum inflammatory biomarkers, and lipid markers. Regarding anthropometric measures, those who engaged in high levels of active transport (≥150 min/wk) had a lower likelihood of being in the top quintile of BMI (adjusted odds ratio [aOR]: 0.62; 95% CI, 0.41–0.91) and waist circumference (aOR: 0.51; 95% CI, 0.31–0.83) groups. These associations were also seen by engaging in higher LTPA (≥150 min/wk), yet with slightly stronger effects (aOR: 0.42; 95% CI, 0.28–0.63 in the top BMI group and aOR: 0.37; 95% CI, 0.25–0.61 in the top waist circumference group). For serum inflammatory biomarkers, we observed a lower likelihood of being in the top quintile groups for circulating CRP (aOR: 0.60; 95% CI, 0.40–0.90) and WBC count (aOR: 0.65; 95% CI, 0.44–0.95) among those engaging in 1 to 149 minutes/week active transport, but not with higher levels of active transport. Higher levels of LTPA (≥150 min/wk) were associated with lower likelihood of having high levels of serum inflammatory biomarkers (aOR: 0.60; 95% CI, 0.42–0.86 in the top CRP group and aOR: 0.58; 95% CI, 0.39–0.87in top WBC group). With respect to lipid markers, no association was seen for levels of active transport or LTPA. Sensitivity analyses using multivariable linear regression models with anthropometric measures and serum markers as continuous variables showed the same results (Supplementary Tables 1–3 [available online]).

Discussion

In this large representative sample of US adults, we found that higher levels of active transport and LTPA were associated with lower levels of adiposity, CRP, and WBC count after adjustment for important confounding variables. Interestingly, no associations were found with lipids. These findings support and add to previous literature demonstrating that overall physical activity is associated with positive health outcomes and lower levels of adiposity and inflammatory biomarkers.[3–5]

The relationship between physical activity and adiposity is one that is known intimately, and a key mechanism driving the association is the increase in daily energy expenditure.[26] Importantly, the present findings show that both active transport and LTPA are associated with a reduction in waist circumference. Waist circumference, in particular, has been shown to have a strong association with type 2 diabetes and metabolic syndrome.[12] Our results support those by others that suggest that a reduction in adiposity can be achieved by an increase in active transport or LTPA.[13–16] Mechanisms resulting in lower levels of WBC count and CRP from sustained participation in physical activity are not well understood, and further work in this area is required. However, epidemiologic data suggest that better fitness is associated with reduced total WBC count due to lower counts in all WBC subclasses.[27,28] In addition, lower BMI has been shown to be

Table 1 Sociodemographic Characteristics and Physical Activity Levels of Adults (20 Y or Older) From the NHANES (2007–2010), by Travel Behavior

	Zero active travel	Lower-level active travel (<150 min/wk)	Higher-level active travel (≥150 min/wk)	*P* value
N	2344	351	444	
Weighted Na	111,450,154	15,443,711	19,385,234	
Age, y, mean (SE)	47.2 (0.5)	42.8 (1.3)	41.7 (1.0)	<.001
Gender, %				.002
Men	49.0	51.8	59.5	
Women	51.0	48.2	40.5	
BMI, %				.05
<24.9	33.9	35.9	42.0	
25.0–29.9	35.7	34.6	35.7	
≥30	30.4	29.5	22.3	
Race, %				.02
Non-Hispanic white	73.2	66.3	65.8	
Non-Hispanic black	9.5	14.5	12.8	
Hispanic and other	17.3	19.2	21.4	
Education, %				<.001
Less than 12th grade	16.1	11.5	34.9	
High school	24.4	21.3	13.8	
Some college	29.2	28.5	34.4	
College graduate or above	30.3	38.7	27.9	
Marital status, %				.02
Live with someone	65.7	57.7	57.9	
Live alone	34.3	42.3	42.1	
Smoking, %				.77
Never smoker	55.9	59.6	56.8	
Former smoker	24.6	22.4	22.6	
Current smoker	19.5	18.0	20.6	
Alcohol consumption, %				.07
Never	26.1	22.9	18.8	
≤1 drink/wk	44.0	40.9	44.6	
>1 drink/wk	29.9	37.2	36.6	
Ratio of family income to poverty, %				.02
<1	10.8	16.2	20.1	
1–1.9	18.2	20.4	19.4	
2–2.9	17.3	10.5	18.5	
3–3.9	13.8	15.0	10.5	
4–4.9	11.9	12.3	7.6	
≥5	28.0	25.6	23.9	
Employment status, %				.21
Employed	68.4	62.3	67.7	
Unemployed	31.6	37.7	32.3	
Chronic illness, %				.001
Yes	36.3	29.7	24.1	
No	63.7	70.3	75.9	
Leisure-time physical activity, %				.01
Inactive	44.4	35.8	44.3	
Insufficiently active	17.2	21.9	10.6	
Sufficiently active	38.4	42.3	45.1	

(continued)

Table 1 (continued)

	Zero active travel	Lower-level active travel (<150 min/wk)	Higher-level active travel (≥150 min/wk)	*P* value
Waist circumference, cm, mean (SE)	96.7 (0.4)	95.6 (1.1)	94.1 (0.9)	.01
Circulating CRP, mg/L, mean (SE)	2.20 (0.05)	1.97 (0.1)	1.91 (0.1)	.02
White blood cell count (1000 cells/μL), mean (SE)	6.54 (0.1)	6.16 (0.1)	6.25 (0.1)	.01
HDL cholesterol, mg/dL, mean (SE)	117.0 (0.9)	111.7 (2.3)	115.7 (2.6)	.40
LDL cholesterol, mg/dL, mean (SE)	54.5 (0.5)	55.0 (1.5)	54.7 (0.9)	.75
Total cholesterol, mg/dL, mean (SE)	197.0 (1.1)	190.8 (2.5)	194.7 (2.8)	.25
Triglycerides, mg/dL, mean (SE)	129.4 (2.5)	122.3 (5.4)	126.3 (5.5)	.45

Abbreviations: BMI, body mass index; CRP, C-reactive protein; HDL, high-density lipoprotein; LDL, low-density lipoprotein; NHANES, National Health and Nutrition Examination Survey.

[a]Weighted sample size to account for the complex survey design (including oversampling), survey nonresponse, and poststratification in the NHANES study.

Table 2 Adjusted Odds Ratios of Being in the Top Quintile of Anthropometric Measures Associated With Time Spent in Active Travel and Leisure-Time Physical Activity

	Body mass index	Waist circumference
Time spent in active travel, min/wk		
0	–	–
1–149	1.04 (0.63–1.71)	1.05 (0.62–1.78)
> –150	0.62 (0.41–0.91)	0.51 (0.31–0.83)
Leisure-time physical activity, min/wk		
0	–	–
1–149	0.69 (0.44–1.06)	0.70 (0.38–1.28)
> –150	0.42 (0.28–0.63)	0.39 (0.25–0.61)

Note: Adjusted for age, gender, race and ethnic group, education level, marital status, smoking status, drinking behavior, ratio of family income to poverty, employment status, chronic illness condition, and leisure-time physical activity (or active transport).

Table 3 Adjusted Odds Ratios of Being in the Top Quintile of Serum Inflammation Biomarkers Associated With Time Spent in Active Travel and Leisure-Time Physical Activity

	Circulating CRP	White blood cell count
Time spent in active travel, min/wk		
0	–	–
1–149	0.60 (0.40–0.90)	0.65 (0.44–0.95)
> –150	0.79 (0.49–1.27)	0.64 (0.39–1.04)
Leisure-time physical activity, min/wk		
0	–	–
1–149	0.86 (0.56–1.32)	0.72 (0.44–1.17)
> –150	0.60 (0.42–0.86)	0.58 (0.39–0.87)

Abbreviation: CRP, C-reactive protein. Note: Adjusted for age, gender, race and ethnic group, body mass index, education level, marital status, smoking status, drinking behavior, ratio of family income to poverty, employment status, chronic illness condition, and leisure-time physical activity (or active transport).

associated with reduced total WBC count and, in particular, with reduced neutrophil, lymphocyte, monocyte, and basophil counts.[29] Physical activity is related to several confounders that are independently associated with lower CRP levels. For example, physical activity is inversely related to age, smoking, hypertension, BMI, waist-to-hip ratio, total and non-HDL-C levels, triglyceride levels, and apolipoprotein B concentrations, whereas these factors are directly related to CRP concentrations.[30] Targeting LTPA and/or active transport may be effective strategies in lowering levels of inflammatory biomarkers and adiposity.

Interestingly, the present study showed that those engaging in 1 to 149 minutes/week of active transport had lower levels of serum inflammatory biomarkers but that those who engaged in the highest levels of active transport did not. The exact reasons behind this are not known, and a plausible explanation is elusive. However, it may be that those who are participating in exceptionally high levels of active transport are experiencing the negative effects of exercise stress on increasing inflammatory markers. Further research is required to test this hypothesis.

In the present study, no associations were found between active transport and markers of lipids. It may be that the activity domains LTPA and active transport are not sufficient to yield a favorable lipid profile, and an increase in overall physical activity is required. However, an improvement in HDL has been observed in relation to higher levels of active transport and LTPA in previous studies.[13,16] Further research in other populations is warranted, using longitudinal designs, in order to understand differences observed between studies.

Key strengths of this study are the large representative sample of the US adult population, objective measures of physical activity, and assessment of active transport for any purpose rather than just for commuting. However, the study is not without limitations. The cross-sectional design prohibits attributing causality to the associations between active transport, LTPA, and health outcomes. Further investigation using a prospective or experimental study design is needed to refute/confirm our results. Because outcomes were based on self-report, reporting biases may exist. It is, for example, known that self-reported walking and cycling might be subject to recall and social desirability biases, a limitation compounded by the use of questions that are potentially cognitively challenging. Future research should utilize objective measures of time spent walking or cycling for travel purposes or time spent physically active during leisure time. The measure of travel mode was relatively crude and did not allow multimodal trips or the daily breakdown of travel behavior to be ascertained. Public transport use was not measured and traveling by public transport usually includes some walking (eg, walking to the bus station or walking from the train station to one's destination).

The present study of a large representative sample of US adults suggests that promoting active transport and/or LTPA may be a

Table 4 Adjusted Odds Ratios of Being in the Top Quintile of Lipid Markers Associated With Time Spent in Active Travel and Leisure-Time Physical Activity

	High-density lipoprotein cholesterol	Low-density lipoprotein cholesterol	Total cholesterol	Triglycerides
Time spent in active travel, min/wk				
0	–	–	–	–
1–149	1.03 (0.63–1.66)	0.60 (0.32–1.13)	0.78 (0.45–1.36)	1.09 (0.65–1.82)
> –150	0.99 (0.59–1.65)	0.95 (0.56–1.60)	1.03 (0.67–1.59)	0.92 (0.58–1.45)
Leisure-time physical activity, min/wk				
0	–	–	–	–
1–149	0.98 (0.58–1.65)	0.97 (0.66–1.44)	0.78 (0.45–1.36)	0.95 (0.58–1.57)
> –150	1.46 (0.97–2.20)	0.97 (0.63–1.48)	1.03 (0.57–1.46)	0.86 (0.59–1.24)

Note: Adjusted for age, gender, race and ethnic group, body mass index, education level, marital status, smoking status, drinking behavior, ratio of family income to poverty, employment status, chronic illness condition, and leisure-time physical activity (or active transport).

beneficial strategy for improving some, but not all, cardiometabolic health outcomes. Specifically, higher levels of active transport and LTPA were associated with lower levels of adiposity, CRP, and WBC count. However, no associations with lipids were found.

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