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Partial Relationships between Health and Fitness Measures in Adults: A Network Analysis

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Abstract **Background**: Evidence supports the associations between many health and fitness measures in the exercise sciences. However, less is known about how these indicators relate to each other after controlling for their shared variance. Furthermore, understanding the relative importance of health and fitness measures may help prioritize education and promotion efforts. The aim of this study was to examine the strength and direction of partial relationships between health and fitness measures in a sample of adults. **Methods**: Data from the 2013-2014 National Health and Nutrition Examination Survey (NHANES) were used and included 3,927 adults 20 to 59 years of age. Six different health and fitness variables were utilized and included grip strength (GRIP, kg), percent body fat (PBF, %), body mass index (BMI, kg/m^2), waist circumference (WC, cm), moderate-to-vigorous physical activity (MVPA, min/week), and perceived general health (HLTH, 1=poor to 5 = excellent). GRIP, PBF, BMI, and WC were assessed objectively by trained professionals using handgrip dynamometer, DEXA, scale with stadiometer, and tape measure, respectively. HLTH was assessed by a single question asking participants to rate their general health and MVPA was assessed by a series of survey questions regarding recreational activity. Two network analyses were conducted: 1) unadjusted and 2) adjusted for sex, age, race, and income. All analyses were performed using SAS and R software (bootnet and qgraph). **Results**: All bivariate Spearman correlation coefficients (r_S) were significant ($p < .05$) ranging from -.14 to -.58 for negative correlations and .07 to .93 for positive correlations. Unadjusted network analysis indicated a strong positive partial relationship between BMI and WC ($r_S = .84$) and a strong negative partial relationship between GRIP and PBF ($r_S = -.73$) with no single central measure. Adjusted network analysis indicated similar partial relationships, however, PBF became a central indicator among the health and fitness measures. **Conclusion**: The findings in this study show that body composition variables such as BMI, WC, and PBF remain associated with each other in a complex health and fitness network. Furthermore, after additionally controlling for demographic variables, PBF may be a standout predictor of health and fitness in adults.

Keywords: *network analysis, fitness, physical activity, perceived health, muscular strength*

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1. Introduction

Health-related fitness is a multidimensional concept that includes the physical fitness attributes possessed by individuals that are also associated with improved health and improved public health [1]. The latest US guidelines for physical activity (PA) stress the importance of health-related fitness with particular attention placed on cardiovascular fitness and muscular fitness [2]. Body composition is also considered a component of health-related fitness with PA interventions aimed at reducing the nation's obesity epidemic from 38.6 percent to 36.0 percent by the year 2030 [3]. Moreover, both concepts of PA and health-related fitness are strongly linked to optimal health-related quality of life in adult populations [4,5,6,7].

Despite the importance placed on the associations between PA, fitness, and health outcomes, few studies have applied techniques that can describe their independent relationships with each other. Network analysis is a set of statistical procedures that describe how a set of variables relate to each other while considering all other variables in the network [8]. Thus, network analysis can examine the extent to which health and fitness measures relate to each other after controlling for their shared variance. Furthermore, network analysis can shed light on the relative importance of several different health and fitness measures, which may help prioritize education and promotion efforts. Hence, one aim of this study was to examine the strength and direction of partial relationships between health and fitness measures by applying network analysis. A second aim was to examine the relative importance among the health and fitness measures and identify potential central measures.

2. Methods

2.1. Study Design

Data for this study came from the 2013-2014 National Health and Nutrition Examination Survey (NHANES) [9]. NHANES is designed to assess health behavior, health status, and nutrition in noninstitutionalized residents of the U.S. NHANES collects data on individuals using different methods including questionnaire interviews, medical/physical examinations, and laboratory tests. The current study used data only from personal interviews (demographics, physical activity, health status) and physical examinations (body measures, muscle strength, and body fat) [10-15]. The sample in the current study was restricted to adults who were 20 to 59 years of age with appropriate health and fitness data. Since the current analysis did not account for the complex survey design used by NHANES, the study data are considered a sample of convenience.

2.2. Variables Utilized

The variables used in this study consisted of grip strength (GRIP), percent body fat (PBF), body mass index (BMI), waist circumference (WC), moderate-to-vigorous physical activity (MVPA), perceived general health (HLTH), age, race, sex, and income.

2.3. Assessment of GRIP and PBF

Grip strength (in kg) was measured in both hands using a handgrip dynamometer that was administered by a health professional. After a practice trial and grip adjustment, participants squeezed the dynamometer as hard as they could with while in the standing position, if able. The test was completed with both hands for a total of three trials with each hand. The largest dynamometer reading for each hand was summed for a combined grip strength score. PBF (in %) was assessed using dual energy X-ray absorptiometry (DXA) and administered by certified radiology technologists. Whole body scans were performed on each participant, and with a Hologic computer system, determined total body fat used in this study.

2.4. Assessment of MVPA and HLTH

MVPA (in min/week) was computed using two preliminary constructed PA variables. First, minutes of vigorous physical activity (VPA) per week and minutes of moderate physical activity (MPA) per week were computed. VPA was assessed from the responses to two questions. The first question asked respondents how many days they participated in vigorous intensity sports, fitness, or recreational activities. The second question asked respondents how much time they spend doing vigorous-intensity activity on a typical day. Multiplying days with minutes yielded VPA measured per week. The same two questions were asked regarding moderate-intensity activities to assess MPA per week. These two physical activity variables were then used to compute minutes of MVPA per week, as follows: MVPA = MPA + 2(VPA). HLTH (in 1 thru 5) was assessed by a single question asking participants to rate their general health. Response options were available that included five rating categories of “excellent”, “Very good”, “Good”, “Fair”, or “Poor”. In this study, HLTH was coded from 1 = “Excellent” to 5 = “Poor”.

2.5. Assessment of BMI and WC

BMI (in kg/m^2) was assessed by a trained health professional from participant’s height and weight with weight measured on a Toledo digital scale and height measured using a stadiometer. WC (in cm) was assessed also by a trained health professional where the measurement site was first marked on the participant’s skin just above the uppermost lateral border of the right ilium at the midaxillary line. A mirror was used to ensure that the steel measuring tape remained parallel to the floor. Measurement was recorded to the nearest 0.1 cm after a normal expiration by the participant.

2.6. Covariates

Demographic variables in this study were used to adjust for their possible confounding effects. Age (in years) was used as a continuous variable and ranged from 20 to 59 years. Race/ethnicity was used as a categorical variable and included groups of White, Black, Hispanic, or Other. Household income (in 1 thru 13) was used as a continuous variable ranging from 1 = “$0-$4,999” to 13 = “$100,000+). Finally, sex was used as a categorical variable.

2.7. Statistical Analyses

Descriptive statistics were computed for all study variables, including means and standard deviations (SDs). Tests of sex differences were performed for study variables using both parametric (independent t tests) and nonparametric methods (Wilcoxon two-sample tests). Due to the skewness, ordinal-level, and/or non-normal nature of the variables in this study, as well as the non-linear association between some pairs of variables, Spearman correlation coefficients (r_S) were used. Two different network analyses were conducted during this study where each included the six (6) health and fitness variables as nodes (i.e., variables) within the network. The first network analysis was unadjusted and included only the six (6) health and fitness nodes. The second network analysis additionally adjusted for age, sex, race, and income. To simplify the interpretation of the adjusted network structure, the health and fitness variables were converted to residuals after regressing each onto the set of covariates. Subsequently, each new health and fitness residuals variable was used as a node in the adjusted network analysis. For the same reasons mentioned above, Spearman correlations were used as the partial correlation edge weights (i.e., partial correlation coefficients) [16]. Weighted network structure graphs were drawn for both the unadjusted and adjusted analyses [16]. The edge weight (line thickness) represents partial correlation strength with blue edge color for positive correlations and red edge color for negative correlations [16]. Additionally, the network structures can identify any central measures in the network by using the Fruchterman-Reingold algorithm and placing a more influential node closer to the center of the network [17]. To further assess network centrality, three different centrality indices were evaluated: 1) strength, 2) closeness, and 3) betweenness [18]. *Strength* takes the sum of absolute edge weights connected to each node. *Closeness* takes the inverse of the sum of distances from one node to all other nodes. *Betweenness* quantifies how often one node is in the shortest path between another node. Finally, multicollinearity was assessed using regression diagnostics and the VIF statistic [19]. Results indicated no multicollinearity in either network analysis, given the large sample size (i.e., all VIFs < 10.0) [20]. All analyses were performed using SAS version 9.4 and R software (bootnet and qgraph) [21-23]. All p-values were reported as 2-sided, all analyses used pairwise deletion, and statistical significance was defined as p-values < 0.05.

3. Results

Table 1 contains descriptive statistics for study variables both overall and by sex. As expected, sex differences were observed for all study variables, less age (p = .706) and HLTH (p = .073), with males showing significantly (p < .05) lower BMI, greater WC, lower PBF, greater GRIP, and greater MVPA. Table 2 contains unadjusted (bottom) and adjusted (top) bivariate Spearman correlation coefficients (r_S) for the health and fitness variables. All correlations were significant (p < .05), less adjusted PBF and GRIP (p = .430), and all with expected directions (i.e., signs). Table 3 contains unadjusted (bottom) and adjusted (top) partial correlation network edge weights for the health and fitness variables. Most notable strong unadjusted partial correlations included BMI and WC (r_S = .836), PBF and GRIP (r_S = -.732), and BMI and PBF (r_S = .344). Notable strong adjusted partial correlations also included BMI and WC (r_S = .798) and PBF and GRIP (r_S = -.238) but also included WC and PBF (r_S = .335).

Figure 1 displays the unadjusted partial correlation network graph for the health and fitness variables. The graph highlights the strong positive partial relationship between BMI and WC and the strong negative partial relationship between GRIP and PBF. The unadjusted graph also highlights the fact that there is no single central health and fitness measure. Figure 2 displays the adjusted network analysis and indicated similar partial relationships, however, PBF became a central indicator among the health and fitness measures. This adjusted network indicates that after controlling for demographic variables (i.e., age, sex, race, and income), PBF becomes a central health and fitness measure.

Table 1. Descriptive statistics for study variables in a convenience sample of adults 20 to 59 years of age, NHANES 2013-2014

	Overall		Male		Female		Sex Diff
Variable	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*p*
Age (yr)	39.3	11.41	39.2	11.54	39.4	11.29	.706
BMI (kg/m^2)	29.2	7.52	28.5	6.48	29.7	8.32	.005
WC (cm)	98.0	17.17	99.0	16.16	97.0	18.01	< .001
PBF (%)	33.1	8.37	27.1	5.83	38.9	6.04	< .001
GRIP (kg)	75.7	21.85	92.9	16.85	59.5	10.81	< .001
HLTH (1 to 5)	3.2	0.95	3.3	0.93	3.2	0.97	.073
MVPA (min/week)	229.2	420.18	286.8	497.67	176.1	324.31	< .001

Note. N = 3,927. Pairwise deletion employed. BMI is body mass index. WC is waist circumference. PBF is percent body fat. GRIP is grip strength. HLTH is perceived general health. MVPA is moderate-to-vigorous physical activity. The larger p-value for the independent t test or Wilcoxon two-sample test is reported.

Table 2. Bivariate Spearman correlation coefficients (r_S) for health and fitness variables in a convenience sample of adults 20 to 59 years of age, NHANES 2013-2014

Variable	BMI	WC	PBF	GRIP	HLTH	MVPA
BMI (kg/m^2)	1.000	.933	.761	.204	-.226	-.097
WC (cm)	.927	1.000	.788	.185	-.248	-.138
PBF (%)	.557	.474	1.000	-.015	-.215	-.172
GRIP (kg)	.098	.171	-.579	1.000	.048	.060
HLTH (1 to 5)	-.268	-.287	-.194	.071	1.000	.192
MVPA (min/week)	-.138	-.176	-.189	.139	.272	1.000

Note. N = 3,927. Pairwise deletion employed. BMI is body mass index. WC is waist circumference. PBF is percent body fat. GRIP is grip strength. HLTH is perceived general health. MVPA is moderate-to-vigorous physical activity. Lower correlations are unadjusted. Upper correlations are adjusted for sex, age, race, and income. All correlations are significant (p < .05), less adjusted PBF and GRIP (p = .430).

Table 3. Partial correlation network edge weights for health and fitness variables in a convenience sample of adults 20 to 59 years of age, NHANES 2013-2014

Variable	BMI	WC	PBF	GRIP	HLTH	MVPA
BMI (kg/m^2)	1.000	.798	.161	.118	-.002	.040
WC (cm)	.836	1.000	.335	.082	-.085	-.030
PBF (%)	.344	.057	1.000	-.238	.000	-.090
GRIP (kg)	.151	.195	-.732	1.000	.071	.037
HLTH (1 to 5)	-.002	-.102	.000	.052	1.000	.152
MVPA (min/week)	.042	-.088	-.012	.090	.214	1.000

Note. N = 3,927. Pairwise deletion employed. BMI is body mass index. WC is waist circumference. PBF is percent body fat. GRIP is grip strength. HLTH is perceived general health. MVPA is moderate-to-vigorous physical activity. Lower partial correlations are unadjusted. Upper partial correlations are adjusted for sex, age, race, and income.

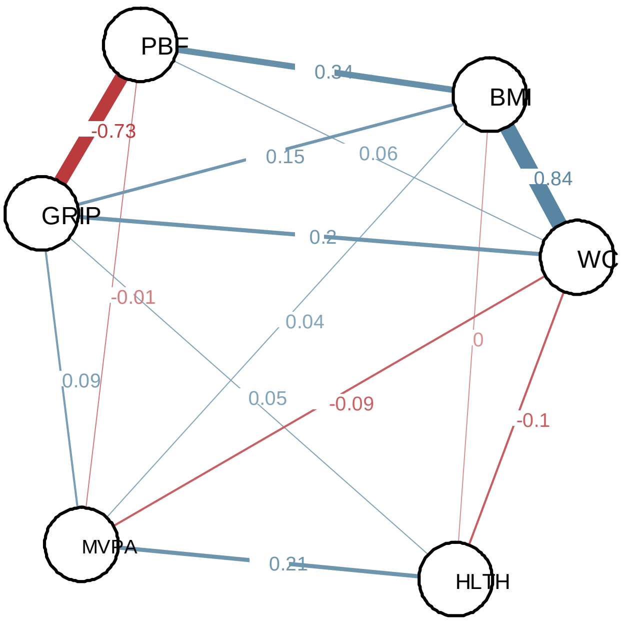

Figure 1. Unadjusted partial correlation network for health and fitness variables in a convenience sample of adults 20 to 59 years of age, NHANES 2013-2014

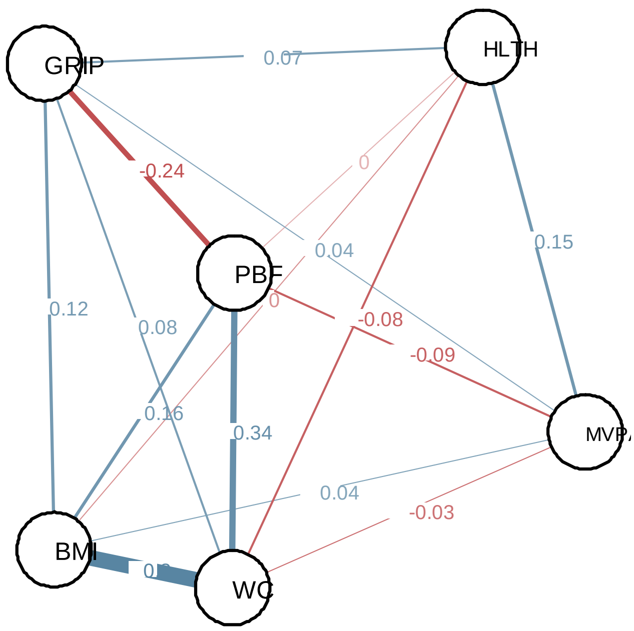

Figure 2. Adjusted partial correlation network for health and fitness variables in a convenience sample of adults 20 to 59 years of age, NHANES 2013-2014

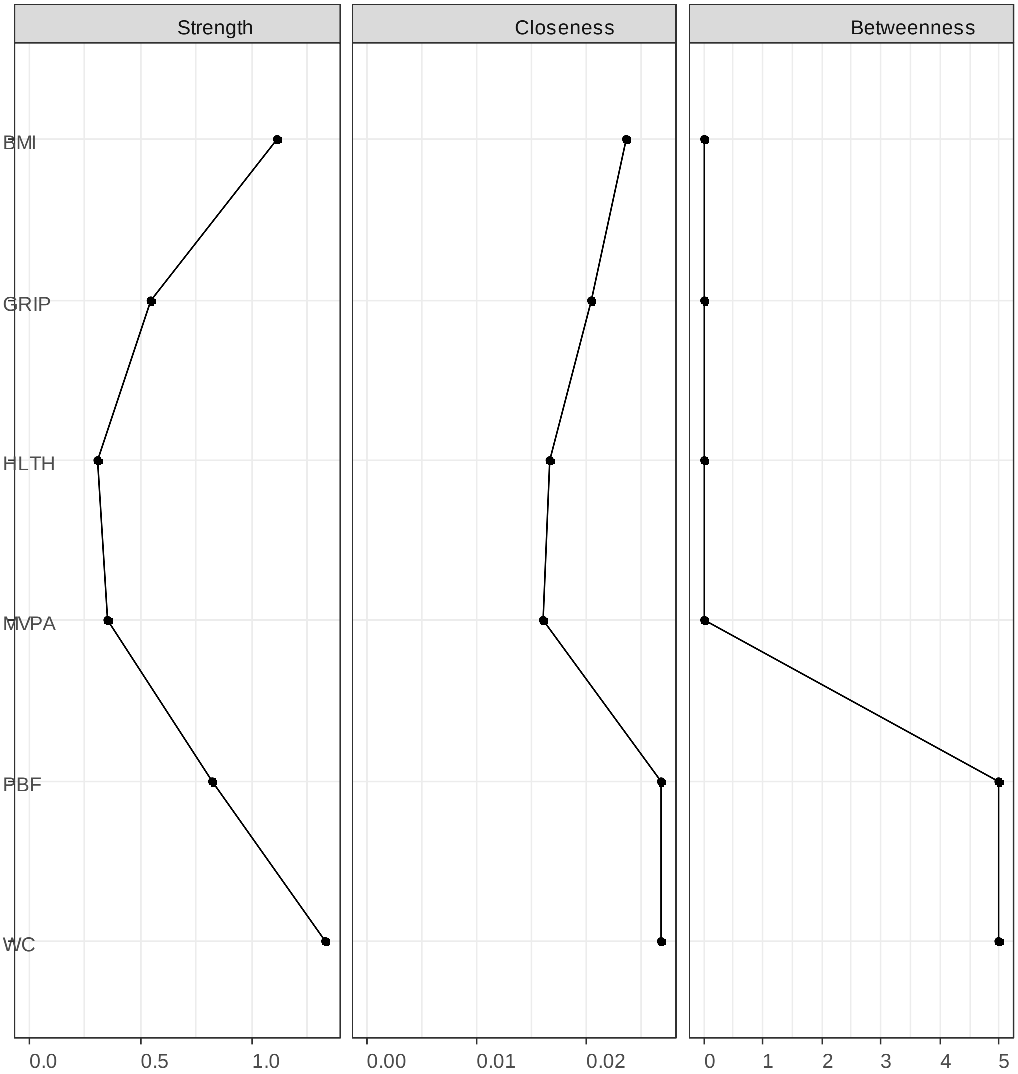

Figure 3. Centrality indices plot for the adjusted partial correlation network (Figure 2) for health and fitness variables in a convenience sample of adults 20 to 59 years of age, NHANES 2013-2014

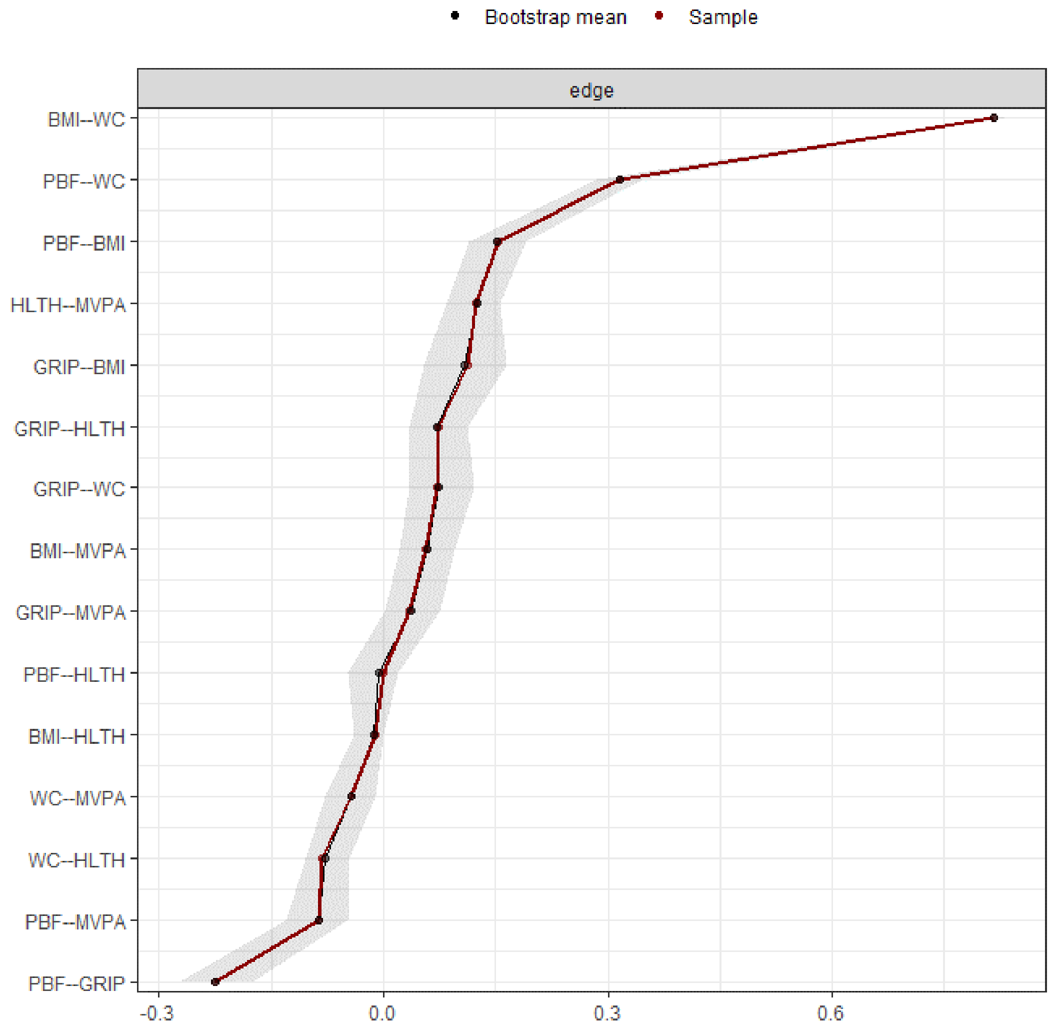

Figure 4. Bootstrapped edge weight estimates with 95% confidence intervals plot for the adjusted partial correlation network (Figure 2) for health and fitness variables in a convenience sample of adults 20 to 59 years of age, NHANES 2013-2014

Figure 3 underscores these results with side-by-side graphs of the centrality indices. The closeness index, a measure of total distance to all other nodes in the network, indicates PBF and WC as strong central measures. Similarly, the betweenness index, a measure of the number of times a node acts as a bridge along the shortest path between two other nodes, indicates PBF and WC as strong central measures. The strength index, a measure of total weights assigned to the node's direct connections, shows that all three body composition measures are strong central measures with WC having greatest strength. This was to be expected given the strong partial correlation between BMI and WC. Therefore, in light of the centrality indices and the adjusted network graph, PBF can be considered a more central measure within the health and fitness network.

Figure 4 shows the plot of bootstrapped edge weight estimates with 95% confidence intervals for the adjusted partial correlation network. This graph indicates a high level of stability regarding the network edge weight parameter estimates. This is judged by the narrow confidence intervals around the node path edge weights. This graph also indicates significant differences between the different edge weights. For example, since the shaded confidence interval area for the GRIP-MVPA path does not overlap (say) the shaded confidence interval area for the PBF-WC path, we can safely infer, with 95% confidence, that these edge weights are significantly different.

4. Discussion

One purpose of this study was to examine the strength and direction of partial relationships between health and fitness measures. These findings support both bivariate and adjusted bivariate associations among the health and fitness variables, including BMI, WC, PBF, GRIP, HLTH, and MVPA. One exception was the non-significant adjusted bivariate correlation between PBF and GRIP. Interestingly, the partial correlations between PBF and GRIP were significant and relatively strong (and negative). Another noteworthy finding is that the bivariate correlations between HLTH and PBF were significant and relatively strong (and negative) but not significant in the partial network analysis. A final noteworthy finding regarding the first aim was that all three body composition variables remained associated with each other in both network analyses. This finding indicates that after accounting for the shared variance of all health and fitness variables (and demographic variables), BMI, WC, and PBF still explain variance for one another.

A second purpose of this study was to examine the relative importance among the health and fitness measures and identify potential central measures. These results indicated, from the unadjusted network analysis, no single central measure. However, after adjusting for demographic variables (age, sex, race, and income), the adjusted network analysis identified PBF as a central measure within the health and fitness structure. This finding highlights firstly the fact that adjustment for demographics change the health and fitness partial associations and secondly the fact that PBF is a standout measure. One way to think of this finding is that altering an adult's PBF may influence other health and fitness variables more efficiently than any other variable in the network.

A strength concerning these results was the use of objective measures of muscular strength (GRIP) and body composition (PBF, BMI, WC). The use of trained health professionals and reliable equipment (handgrip dynamometer, DXA, floor scale, stadiometer, tape measure) add validity to these findings. Another strength concerning these results was its use of a large sample size from a diverse population. Large samples are necessary and preferred for issues related to power and edge weight estimate accuracy and therefore add strength to these findings [24].

One limitation concerning these results is the cross-sectional nature of the data. Cross-sectional data cannot provide cause-and-effect evidence regarding the health and fitness associations. Specifically, these results do not imply that improving one's body fat (PBF) will in turn improve their muscular strength (GRIP). An experimental study should be conducted to address such cause-and-effect associations. Another limitation concerning these results is the use of a convenience sample. NHANES requires the use of complex sampling procedures to validly generalize to all US adults in this age group, however, such complex statistical procedures were not incorporated into the network analyses. Therefore, generalizations should be interpreted with caution. Given this fact, the large sample size from a diverse population arguably makes this sample less biased than many other convenience samples used in correlational research. A final limitation regarding these results is the use of self-report assessments for both perceived health (HLT) and recreational PA (MVPA). Data from self-reported questionnaires have certain biases over more objective means of measurement. However, NHANES includes current health and PA items that are generally considered reliable for adult populations [25,26].

5. Conclusions

The findings in this study show that body composition variables such as BMI, WC, and PBF remain associated with each other in a complex health and fitness network. Furthermore, after additionally controlling for demographic variables, PBF may be a standout predictor of health and fitness in adults. Employing network analysis can help us better understand health and fitness by examining the complex relationships between several different assessment measures. Additionally, network analysis can help us identify measures that are more influential within the health and fitness system.

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