Journal of Exercise Science & Fitness 20 (2022) 323–327

Contents lists available at ScienceDirect

Journal of Exercise Science & Fitness

journal homepage: www.elsevier.com/locate/jesf

Cardiometabolic factors explaining the association between physical activity and quality of life: U.S. National Health and Nutrition Examination Survey

Frederick H. Huang [a], Jung-Hua Liu [b], I-Chan Huang [c, *]

[a] Memphis University School, Memphis, TN, USA
[b] Patient-Reported Outcomes Education Group, Germantown, TN, USA
[c] St. Jude Children's Research Hospital, Memphis, TN, USA

ARTICLE INFO

Article history:
Received 26 January 2022
Received in revised form
27 July 2022
Accepted 28 July 2022
Available online 1 August 2022

Keywords:
Cardiometabolic risk
National health and nutrition examination survey
Physical activity
Quality of life

ABSTRACT

Purpose: To test the Clustered Cardiometabolic Risk (CCMR) factor explaining the relationship between physical activity and physical quality of life (QOL).

Methods: Using the U.S. National Health and Nutrition Examination Survey 2003–2006, 2,445 adults completed the CDC Healthy Days Questionnaire for measuring QOL, wore the accelerometer for assessing physical activity pattern (PAP), and completed triglyceride, glucose, serum insulin, waist circumference, blood pressure, and HDL-cholesterol tests from which the CCMR factor was created. Physical QOL was classified as poor (≥14 days with poor physical health within past 30 days) vs. good (<14 days). We classified PAP by moderate-to-vigorous physical activity (MVPA), light-intensity physical activity (LIPA), and sedentary behavior (SB). We defined MVPA, LIPA, and SB as ≥2020 counts/minute, 100–2019 counts/minute, and ≤99 counts/minute, respectively. We further classified PAP status as unhealthy (MVPA <150 min/week & SB>LIPA) or healthy (MVPA <150 min/week & SB<LIPA, or MVPA ≥150 min/week regardless of SB>LIPA or SB<LIPA). Logistic regressions analyzed the association between unhealthy PAP and poor physical QOL, adjusting for the CCMR factor, age, sex, education, and smoking behavior.

Results: Compared with having healthy PAP, individuals having unhealthy PAP had an elevated risk of poor physical QOL (OR = 1.96; 95% CI = 1.42–2.72). However, this association was explained by higher levels of the CCMR factor (OR = 1.46; 95% CI = 1.07–1.99) through poorer serum insulin (OR = 1.35; 95% CI = 1.04–1.75) and waist circumference (OR = 1.23; 95% CI = 1.02–1.50).

Conclusion: The CCMR factor (typically insulin and waist circumference) explained the association between unhealthy physical activity and poor physical QOL.

© 2022 The Society of Chinese Scholars on Exercise Physiology and Fitness. Published by Elsevier (Singapore) Pte Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

1. Introduction

More than 70% of adult Americans perform insufficient physical activity.[1] A report from the U.S. Secretary of Health and Human Services suggests that achieving recommended levels of physical activity and decreasing sedentary behavior can benefit health outcomes.[2] Physiological research found positive effects of increased physical activity on cardio-related biomarkers (e.g., triglycerides, glucose, insulin, HDL-cholesterol, C-reactive protein, neutrophil levels, and homeostatic model assessment-%B or -%S).[3,4] Individuals performing regular physical activity also show better quality of life (QOL).[5,6]

Although the association between physical activity and QOL has been examined previously, specific biological mechanisms, especially the Clustered Cardiometabolic Risk (CCMR) factor consisting of triglyceride, HDL-cholesterol, fasting plasma glucose, fasting serum insulin, waist circumference, systolic blood pressure, and diastolic blood pressure,[7,8] for explaining physical activity-QOL associations have not been identified. This study tested how the CCMR factor explains the association between physical inactivity/sedentary behaviors and poor QOL in a national representative sample.

* Corresponding author. Department of Epidemiology and Cancer Control, St. Jude Children's Research Hospital, MS-735, 262 Danny Thomas Place, Memphis, TN, 38105, USA.
E-mail address: i-chan.huang@stjude.org (I.-C. Huang).

https://doi.org/10.1016/j.jesf.2022.07.005
1728-869X/© 2022 The Society of Chinese Scholars on Exercise Physiology and Fitness. Published by Elsevier (Singapore) Pte Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

2. Methods

This cross-sectional study included 2,445 adults aged ≥18 years who partook in the U.S. National Health and Nutrition Examination Survey (NHANES)[9] between 2003 and 2006 (Supplementary Fig. 1). Participants completed the CDC Healthy Days Questionnaire for measuring QOL, wore the ActiGraph accelerometer for assessing physical activity pattern (PAP), and completed laboratory tests for collecting biomarkers (triglyceride, HDL-cholesterol, fasting plasma glucose, fasting serum insulin, waist circumference, systolic blood pressure, and diastolic blood pressure) from which the CCMR factor was created.

We calculated the CCMR factor based on the tests of triglyceride, HDL-cholesterol, fasting plasma glucose, fasting serum insulin, waist circumference, systolic blood pressure, and diastolic blood pressure. We normalized ($\log_{10}$) the participants' triglyceride, glucose, and insulin values, and calculated the standardized z-scores (i.e., (value - mean)/standard deviation) for each variable. We inverted the HDL-cholesterol z-scores to unify the direction with other biomarkers of the CCMR factor (higher scores for higher risk), averaged the systolic and diastolic blood pressure z-scores, and averaged the z-scores of the six CCMR biomarkers for each participant.[7]

For physical activity measurement, participants wore the ActiGraph accelerometer for one week during waking hours except for activities in the water. A minimum of 10 h wear time per day for ≥4 days is deemed valid data for analysis.[10] We classified PAP by moderate-to-vigorous physical activity (MVPA), light-intensity physical activity (LIPA), and sedentary behavior (SB). For each participant, we defined MVPA as ≥2020 counts per minute, LIPA as between 100 and 2019 counts per minute, and SB as ≤99 counts per minute.[10] We further classified PAP status as unhealthy (MVPA <150 min per week & SB>LIPA) or healthy (MVPA <150 min per week & SB<LIPA, or MVPA ≥150 min per week regardless of SB>LIPA or SB<LIPA).[11] For QOL, we focused on physical-related QOL, which was measured by the CDC Healthy Days

Table 1
Characteristics of study participants (N = 2445).

Characteristics	N	Weighted %
Age at study (years)		
18–39	882	34.1
40–59	706	41.0
60–79	679	21.2
≥80	178	3.7
Sex		
Male	1237	49.8
Female	1208	50.2
Race/ethnicity		
Non-Hispanic white	1292	74.9
Non-Hispanic black	457	8.8
Hispanic	594	10.7
Other	102	5.6
Educational attainment		
Less than high school	364	6.8
High school graduate/general education development	887	34.0
Some college or associate degree	702	32.6
College graduate or above	490	26.6
Family income (poverty income ratio)		
<1	355	8.3
1–2.99	957	34.8
≥3	1021	56.9
Smoking status		
Never smoker	1147	50.2
Former smoker	676	27.8
Current smoker	434	22.0
Number of chronic health conditions		
0	1481	62.1
1	609	25.1
2	182	6.3
3	96	3.9
4+	77	2.7
Physical activity pattern		
<150 min/week MVPA and negative LIPA-SED balance	1250	47.1
<150 min/week MVPA and positive LIPA-SED balance	216	8.8
≥150 min/week MVPA and negative LIPA-SED balance	631	29.0
≥150 min/week MVPA and positive LIPA-SED balance	348	15.1
Quality of life (CDC physical unhealthy days)		
<14 days	2184	90.7
≥14 days	259	9.3
Biomarkers	Mean ± SD	Weighted Mean
Clustered cardiometabolic risk factor	−0.01 ± 0.61	−0.03
Triglyceride (mmol/L)	1.64 ± 1.36	1.65
HDL-cholesterol (mmol/L)	1.43 ± 0.41	1.43
Fasting plasma glucose (mmol/L)	5.79 ± 1.79	5.66
Fasting serum insulin (pmol/L)	67.69 ± 64.52	64.07
Waist circumference (cm)	97.73 ± 15.21	97.82
Systolic blood pressure (mmHg)	125.00 ± 20.34	122.87
Diastolic blood pressure (mmHg)	68.74 ± 13.93	70.29

Note, MVPA = moderate-to-vigorous physical activity; LIPA = light-intensity physical activity; SED = sedentary behavior.

Questionnaire: "How many days during the past 30 days was your physical health not good?" Based on previous studies, we classified each participant's physical QOL as poor (≥14 days) or good (<14 days) status.[6]

Logistic regressions were performed to analyze how the CCMR factor explains the association between unhealthy (vs. healthy) PAP and poor (vs. good) physical QOL. Four separate models were implemented to account for the influence of different covariates. In Model 1, the association between unhealthy PAP and poor physical QOL was tested without adjusting for covariates. In Model 2, the association between PAP and QOL was tested by adjusting for age, sex, educational attainment, and smoking status, which were selected based on significant bivariate associations ($p < 0.1$) between physical activity and QOL. Model 3 added the CCMR factor to the variables used in Model 2. Extending from Model 3, Models 4a-4f replaced the CCMR factor with the six individual biomarkers of the CCMR factors to delineate the contribution of each biomarker to the PAP-QOL associations.

SPSS Statistics 27 was used for all analyses with the consideration of 4-year sample weights.

3. Results

Table 1 shows the characteristics of participants (N = 2,445). More than 47% of participants had an unhealthy PAP and over 9% of participants had poor physical QOL.

Table 2 shows the association between unhealthy PAP and poor physical QOL with and without adjusting for the CCMR factor and

Table 2
Associations between PAP and QOL adjusting for the CCMR, six individual CCMR biomarkers, and other covariates.

Factors	Model 1 OR (95% CI)	Model 2 OR (95% CI)	Model 3 OR (95% CI)	Model 4a OR (95% CI)	Model 4b OR (95% CI)	Model 4c OR (95% CI)	Model 4d OR (95% CI)	Model 4e OR (95% CI)	Model 4f OR (95% CI)
Physical activity pattern									
Healthy pattern	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.
Unhealthy pattern	**1.96*** (1.42, 2.72)**	**1.49* (1.03, 2.17)**	1.36 (0.93, 2.00)	**1.47* (1.01, 2.12)**	**1.46* (1.00, 2.13)**	1.46 (0.99, 2.15)	1.33 (0.91, 1.94)	1.38 (0.94, 2.02)	**1.49* (1.02, 2.18)**
Age at study (years)		**1.02*** (1.01, 1.03)**	**1.02** (1.01, 1.03)**	**1.02** (1.01, 1.03)**	**1.02*** (1.01, 1.03)**	**1.02** (1.01, 1.03)**	**1.02*** (1.02, 1.04)**	**1.02** (1.01, 1.03)**	**1.02*** (1.01, 1.03)**
Sex									
Male		Ref.	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.
Female		0.95 (0.61, 1.48)	1.09 (0.68, 1.74)	0.96 (0.61, 1.51)	1.02 (0.63, 1.64)	0.97 (0.62, 1.51)	1.02 (0.65, 1.62)	1.07 (0.68, 1.68)	0.95 (0.60, 1.50)
Educational attainment									
College graduate or above		Ref.	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.
Some college or AA		1.65 (0.95, 2.85)	1.56 (0.91, 2.68)	1.64 (0.95, 2.83)	1.63 (0.95, 2.80)	1.61 (0.93, 2.79)	1.58 (0.92, 2.72)	1.59 (0.92, 2.74)	1.65 (0.95, 2.85)
High school graduate/GED		**1.83* (1.02, 3.30)**	1.67 (0.94, 2.97)	**1.80* (1.00, 3.25)**	**1.80* (1.01, 3.22)**	1.75 (0.97, 3.16)	1.68 (0.95, 3.00)	1.73 (0.98, 3.08)	**1.83* (1.02, 3.30)**
Less than high school		**2.32* (1.23, 4.38)**	**2.12* (1.17, 3.86)**	**2.28* (1.22, 4.25)**	**2.25* (1.23, 4.13)**	**2.18* (1.18, 4.03)**	**2.17* (1.17, 4.04)**	**2.28* (1.21, 4.29)**	**2.32* (1.22, 4.39)**
Smoking status									
Never smoker		Ref.	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.
Former smoker		0.97 (0.64, 1.47)	0.98 (0.65, 1.47)	0.97 (0.64, 1.46)	0.98 (0.65, 1.48)	0.98 (0.65, 1.47)	0.97 (0.66, 1.45)	0.97 (0.64, 1.47)	0.97 (0.64, 1.48)
Current smoker		1.24 (0.85, 1.80)	1.27 (0.87, 1.86)	1.23 (0.85, 1.77)	1.23 (0.85, 1.79)	1.25 (0.86, 1.83)	1.32 (0.91, 1.92)	1.28 (0.88, 1.86)	1.24 (0.86, 1.78)
CCMR factor			**1.46* (1.07, 1.99)**						
Six biomarkers of CCMR factor									
Triglyceride (mmol/L)				1.07 (0.91, 1.27)					
HDL-cholesterol (mmol/L)					1.10 (0.92, 1.32)				
Fasting plasma glucose (mmol/L)						1.15 (0.98, 1.35)			
Fasting serum insulin (pmol/L)							**1.35* (1.04, 1.75)**		
Waist circumference (cm)								**1.23* (1.02, 1.50)**	
Average blood pressure (mmHg)									1.00 (0.80, 1.25)
Model fit									
−2 Log likelihood (-2LL)	1628.34 (1)	1515.49 (8)	1503.14 (9)	1513.85 (9)	1513.34 (9)	1506.62 (9)	1505.13 (9)	1500.09 (9)	1515.19 (9)
-2LL change (reference: Model 1)[a]	NA	−112.85 (7)	−125.20 (8)	−114.49 (8)	−115.00 (8)	−121.72 (8)	−123.21 (8)	−128.25 (8)	−113.15 (8)
X^2-statstic (p-value)	NA	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
-2LL change (reference: Model 2)[a]	NA	NA	−12.35 (1)	−1.64 (1)	−2.15 (1)	−8.87 (1)	−10.36 (1)	−15.40 (1)	−0.30 (1)
X^2-statstic (p-value)	NA	NA	<0.001	0.200	0.143	0.003	0.001	<0.001	0.584

Note, CCMR = clustered cardiometabolic risk; NA = not applicable; PAP = physical activity pattern; QOL = quality of life.
*p < 0.05, **p < 0.01, ***p < 0.001.
[a] Compared to Model 1 (the reference model), model fits were significantly improved for Model 2 and Model 3, as suggested by the significant X^2-statistic. The magnitude of improvement was more salient for Model 3 compared to Model 2.

covariates. Models 1 and 2 suggest that compared with participants having healthy PAP, those having unhealthy PAP had an elevated risk of poor physical QOL (OR = 1.96; 95% CI = 1.42, 2.72 in Model 1; OR = 1.49; 95% CI = 1.03, 2.17 in Model 2). However, Model 3 suggests that the association between unhealthy PAP and poor physical QOL was explained after adding the CCMR factor and other covariates. Specifically, there was a significant association between the CCMR factor and poor physical QOL (OR = 1.46; 95% CI = 1.07, 1.99), whereas the association between unhealthy PAP and poor physical QOL became not significant (OR = 1.36; 95% CI = 0.93, 2.00).

In Model 4, separate analyses of the six individual biomarkers of the CCMR factor reveals that a poorer status of fasting serum insulin (OR = 1.35; 95% CI = 1.04, 1.75) and waist circumference (OR = 1.23; 95% CI = 1.02, 1.50), instead of unhealthy PAP, was significantly associated with poor physical QOL.

4. Discussion

This study demonstrates that unhealthy physical activity behaviors were associated with poor physical QOL through the influences of cardiometabolic risks measured by the CCMR factor. Among these cardiometabolic factors, interestingly, serum insulin and waist circumference, instead of triglyceride, glucose, blood pressure, and HDL-cholesterol, significantly explained the association between physical activity and QOL. From a statistical viewpoint, serum insulin and waist circumference were moderately correlated (a correlation coefficient 0.54 among study participants), and the magnitude was higher than with triglyceride, glucose, blood pressure, and HDL-cholesterol (coefficients <0.35). From a clinical viewpoint, physically inactive individuals often have higher insulin concentrations and unhealthy waist size than other cardiometabolic factors,[12,13] both of which are associated with a higher burden of chronic conditions and poorer QOL.[14–16]

The evidence of the CCMR factor in explaining the association between unhealthy PAP and poor physical QOL paves the foundation for future clinical practice and research to improve QOL of general populations through health promotion interventions targeting the increase of physical activity to meet the recommended guidelines, especially using a scalable, longitudinal design. Emerging evidence suggests that increased physical activity over time can lead to decreased cardiovascular risks,[17] and the replacement of sedentary time with a moderate-to-vigorous intensity of physical activity is associated with improved cardiovascular health over a 10-year observation.[18] Future studies can extend our design by considering novel biomarkers (e.g., circulating angiogenetic factors, and antiatherogenic adaptations in vascular function and structure) to elucidate complex cardiometabolic pathways delineating physical activity and QOL associations.[19]

The strengths of this study include the use of a representative national sample, an objective measure of physical activity using the Actigraph accelerometer, and the incorporation of several important biomarkers. However, this study has several limitations. First, the use of a cross-sectional design cannot elucidate the causal relationship between physical activity, cardiometabolic biomarkers, and physical QOL. Additionally, we focused only on the CDC Healthy Days measure for assessing physical QOL. Longitudinal studies are warranted to replicate our findings using other QOL measures (e.g., the SF-36 or PROMIS).

In conclusion, cardiometabolic biomarkers are significant biological factors explaining the relationship between unhealthy physical activity behaviors and poor physical QOL.

Author contributions

Concept and design: Huang IC.
Administrative support: Liu JH.
Provision of study materials: NHAMES website (publicly available).
Assembly of data: Huang FH, Liu JH.
Data analysis and interpretation: Huang FH, Liu JH, Huang IC.
Manuscript writing: Huang FH, Huang IC.
Editing and final approval of manuscript: all authors.

Funding

None.

Declaration of competing interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jesf.2022.07.005.

References

1. Piercy KL, Troiano RP, Ballard RM, et al. The physical activity guidelines for Americans. *JAMA*. 2018;320(19):2020–2028. https://doi.org/10.1001/jama.2018.14854.
2. 2018 Physical Activity Guidelines Advisory Committee. *2018 Physical Activity Guidelines Advisory Committee Scientific Report. Washington D.C.: U.S. Department of Health and Human Services*. 2018.
3. Healy GN, Matthews CE, Dunstan DW, Winkler EAH, Owen N. Sedentary time and cardio-metabolic biomarkers in US adults: NHANES 2003-06. *Eur Heart J*. 2011;32(5):590–597. https://doi.org/10.1093/eurheartj/ehq451.
4. Loprinzi PD, Sheffield J, Tyo BM, Fittipaldi-Wert J. Accelerometer-determined physical activity, mobility disability, and health. *Disabil Health J*. 2014;7(4):419–425. https://doi.org/10.1016/j.dhjo.2014.05.005.
5. Anokye NK, Trueman P, Green C, Pavey TG, Taylor RS. Physical activity and health related quality of life. *BMC Publ Health*. 2012;12:624. https://doi.org/10.1186/1471-2458-12-624.
6. Kim J, Im JS, Choi YH. Objectively measured sedentary behavior and moderate-to-vigorous physical activity on the health-related quality of life in US adults: the National Health and Nutrition Examination Survey 2003-2006. *Qual Life Res Int J Qual Life Asp Treat Care Rehabil*. 2017;26(5):1315–1326. https://doi.org/10.1007/s11136-016-1451-y.
7. Wijndaele K, Orrow G, Ekelund U, et al. Increasing objectively measured sedentary time increases clustered cardiometabolic risk: a 6 year analysis of the ProActive study. *Diabetologia*. 2014;57(2):305–312. https://doi.org/10.1007/s00125-013-3102-y.
8. Lamb MJE, Westgate K, Brage S, et al. Prospective associations between sedentary time, physical activity, fitness and cardiometabolic risk factors in people with type 2 diabetes. *Diabetologia*. 2016;59(1):110–120. https://doi.org/10.1007/s00125-015-3756-8.
9. Us Centers for Disease Control and Prevention. NHANES questionnaires, datasets, and related documentation. November 7, 2021 https://wwwn.cdc.gov/nchs/nhanes/Default.aspx.
10. Troiano RP, Berrigan D, Dodd KW, Mâsse LC, Tilert T, McDowell M. Physical activity in the United States measured by accelerometer. *Med Sci Sports Exerc*. 2008;40(1):181–188. https://doi.org/10.1249/mss.0b013e31815a51b3.
11. Loprinzi PD, Lee H, Cardinal BJ. Daily movement patterns and biological markers among adults in the United States. *Prev Med*. 2014;60:128–130. https://doi.org/10.1016/j.ypmed.2013.12.017.
12. Kriska AM, Pereira MA, Hanson RL, et al. Association of physical activity and serum insulin concentrations in two populations at high risk for type 2 diabetes but differing by BMI. *Diabetes Care*. 2001;24(7):1175–1180. https://doi.org/10.2337/diacare.24.7.1175.
13. Hamasaki H, Noda M, Moriyama S, et al. Daily physical activity assessed by a triaxial accelerometer is beneficially associated with waist circumference, serum triglycerides, and insulin resistance in Japanese patients with

prediabetes or untreated early type 2 diabetes. *J Diabetes Res*. 2015;2015: 526201. https://doi.org/10.1155/2015/526201.
14. Rahman MS, Hossain KS, Das S, et al. Role of insulin in health and disease: an update. *Int J Mol Sci*. 2021;22(12):6403. https://doi.org/10.3390/ijms22126403.
15. Ross R, Neeland IJ, Yamashita S, et al. Waist circumference as a vital sign in clinical practice: a consensus statement from the IAS and ICCR working group on visceral obesity. *Nat Rev Endocrinol*. 2020;16(3):177–189. https://doi.org/10.1038/s41574-019-0310-7.
16. Alonso J, Ferrer M, Gandek B, et al. Health-related quality of life associated with chronic conditions in eight countries: results from the International Quality of Life Assessment (IQOLA) Project. *Qual Life Res*. 2004;13(2):283–298. https://doi.org/10.1023/b:qure.0000018472.46236.05.
17. Leskinen T, Stenholm S, Heinonen OJ, et al. Change in physical activity and accumulation of cardiometabolic risk factors. *Prev Med*. 2018;112:31–37. https://doi.org/10.1016/j.ypmed.2018.03.020.
18. Whitaker KM, Pettee Gabriel K, Buman MP, et al. Associations of accelerometer-measured sedentary time and physical activity with prospectively assessed cardiometabolic risk factors: the CARDIA study. *J Am Heart Assoc*. 2019;8(1). https://doi.org/10.1161/JAHA.118.010212. e010212.
19. Fiuza-Luces C, Santos-Lozano A, Joyner M, et al. Exercise benefits in cardiovascular disease: beyond attenuation of traditional risk factors. *Nat Rev Cardiol*. 2018;15(12):731–743. https://doi.org/10.1038/s41569-018-0065-1.