Effects of different types and frequencies of physical activity on the homeostatic model assessment of insulin resistance

Junhyun Kwon,[1,2] Woorim Kim,[1,2] Sang Ah Lee,[1,2] Dongwoo Choi,[1,2] Eun-Cheol Park[2,3]

[1]Department of Public Health, Graduate School, Yonsei University, Seoul, Republic of Korea
[2]Institute of Health Services Research, Yonsei University, Seoul, Republic of Korea
[3]Department of Preventive Medicine, Yonsei University College of Medicine, Seoul, Republic of Korea

Correspondence to
Dr Eun-Cheol Park, Department of Preventive Medicine and Institute of Health Services Research, Yonsei University College of Medicine, Seoul 120-752, Republic of Korea; ecpark@yuhs.ac

Accepted 30 November 2018
Published Online First 18 January 2019

To cite: Kwon J, Kim W, Lee SA, *et al*. *J Investig Med* 2019;**67**:841–849.

ABSTRACT
This study analyzed the type and frequency of physical activity that most effectively reduces the homeostatic model assessment of insulin resistance (HOMA2-IR) among adults (≥19 years) in Asia. We used national representative data from 1645 men and 2272 women who participated in the Korea National Health and Nutrition Examination Survey in 2015 were included in the analysis. The effects of different types and frequencies of physical activity on HOMA2-IR were investigated using a multiple regression analysis. Compared with no activity, moderate-to-vigorous physical activity (MVPA) ≥5 times per week (β: −0.214, p≤0.0198) and walking and MVPA ≥5 times per week (β: −0.183, p≤0.0049) were negatively associated with HOMA2-IR. In the subgroup analysis, the strongest effect was observed among overweight men. Additionally, walking plus MVPA ≥5 times per week had the strongest effect on men with a higher-than-recommended daily calorie intake (β: −0.350, p≤0.0030). Therefore, in conclusion, the appropriate type and frequency of physical activity can help reduce HOMA2-IR in South Korean men, especially those who are overweight and/or have a higher-than-recommended daily calorie intake.

Significance of this study

What is already known about this subject?
- The homeostatic model assessment of insulin resistance (HOMA2-IR) is convenient to assess IR.
- Both abdominal obesity and IR associated strongly with type 2 diabetes are commonly associated with physical activity (PA).
- PA has been associated with reductions in the risks of mortality and morbidity associated with chronic diseases, prevention of obesity, cardiovascular disease, cancer, and enhanced insulin sensitivity.

What are the new findings?
- In this study, walking plus moderate-to-vigorous physical activity (MVPA) ≥5 times per week was associated with the lowest HOMA2-IR levels, followed by MVPA ≥5 times per week; by contrast, generally walking alone did not affect the HOMA2-IR.
- Among men with overweight body mass index (BMI), walking plus MVPA, and only walking were also associated with lower HOMA2-IR.
- Walking plus MVPA ≥5 times per week and MVPA ≥5 times per week were effective.
- A reduction in the HOMA2-IR could be better achieved by exercising the most appropriate type and frequency of PA according to the subject's individual characteristics.

How might these results change the focus of research or clinical practice?
- Our study can suggest the most appropriate type and frequency of PA for reducing HOMA2-IR, and to make particularly specific inferences and recommendations for individuals with an overweight BMI. Therefore, it can help prevent the IR through PA.

INTRODUCTION
Diabetes is an important public health issue worldwide.[1] Considering the financial effects of diabetes, numerous countries are taking steps to comply with the goals of the WHO Non-Communicable Disease Global Action Plan 2013–2020.[2]

Most cases of diabetes are considered type 2, the risk of which is closely related to insulin resistance (IR).[3–5] Currently, many IR measurement methods are available. Although the gold standard euglycemic-hyperinsulinemic clamp test and intravenous glucose tolerance test are among the most typical methods for assessing IR,[6 7] they are relatively time consuming and costly.[8] By contrast, the homeostatic model assessment of IR (HOMA2-IR) is much more convenient because it can be used when only 2 fasting glucose and fasting insulin concentrations are available.[9]

Abdominal obesity has a major influence on IR,[10] such that even those with normal weight exhibited an increase in IR if they had developed abdominal obesity, which make the carotid artery's endogenous membrane dreadful.[11] In brief, abdominal obesity directly affects IR. Notably, both of these variables associated strongly with type 2 diabetes are commonly associated with physical activity (PA).[12 13] In previous studies, PA has been associated with reductions in the risks of mortality and morbidity associated with chronic diseases, as well as the prevention of obesity,[14 15] cardiovascular disease,[16] cancer,[17 18] and enhanced insulin sensitivity.[19] Conversely, insufficient PA can lead to an increased IR.[20] Despite the obvious links between PA and chronic disease prevention, few studies have investigated the association between PA and HOMA2-IR. Therefore, this study aimed to examine the effects of the type and frequency of PA on IR, using data from the Korea National Health and Nutrition Examination Survey (KNHANES). Specifically, we evaluated the influences of type and frequency of PA on IR and differences in the body mass index (BMI) and daily caloric intake. Furthermore, this study attempted to suggest the type and frequency of PA that could most effectively reduce the individual HOMA2-IR.

METHODS

Study population

This study used data from the KNHANES, which has been conducted by the Korean Centers for Disease Control and Prevention to assess the health and nutritional status of the Korean population since 1998. This national, cross-sectional, population-based survey evaluates the health and nutritional statuses of non-institutionalized Korean civilians using health interviews and examinations, as well as nutrition surveys. Survey stratification is based on 16 metropolitan cities and provinces, as well as administrative divisions and dwelling units.

The 2015 KNHANES baseline data sets included 3381 and 3999 individuals, respectively. Among the 7380 total eligible respondents, subjects younger than 19 years of age and those with missing data for variables used in this study were excluded. Finally, 3917 subjects, including 1645 men and 2272 women, were included in this study.

Measures

Dependent variable

This study aimed to investigate differences in the HOMA2-IR, a simple and useful indicator of IR, according to the type and frequency of PA among South Korean adults. The HOMA2-IR was the dependent variable. Although many methods for quantifying the measured IR are available, the HOMA2-IR is considered accurate and is widely used in clinical studies.[21] In this study, we used the HOMA calculator version 2.2.3 (available from http://www.dtu.ox.ac.uk).[22] This method can be easily calculated based on measured fasting plasma blood glucose (3.5–25.0 mmol/L) and fasting plasma insulin (20–400 pmol/L) concentrations.

HOMA2-IR, an indicator of IR, is relatively simple and also provides accurate values. It has been used in many clinical studies and is a reliable measure. Hence, it is believed that the use of HOMA2-IR is still being updated.

Variables of interest

In this study, the independent variable was PA, which was classified by type plus frequency for analysis. The PA criteria included exercise during leisure time but excepted PA during work. The PA type was subcategorized into walking and moderate-to-vigorous physical activity (MVPA). MVPA included vigorous intensity, moderate intensity, strength, and flexibility exercises, all of which were used to examine the effect of PA on the HOMA2-IR. With respect to exercise frequency, the subjects were also divided into 3 groups: none, ≥5 times per week, and <5 times per week. We combined these 2 variables of PA type plus frequency, which was categorized as follows: no activity, walking <5 times, walking ≥5 times, MVPA <5 times, MVPA ≥5 times, walking and MVPA <5 times, and walking and MVPA ≥5 times.

Covariates

The characteristics of the individual study subjects were stratified by sex and included in this study as covariates. The individual characteristics included age (19–29, 30–39, 40–49, 50–59, 60–69, and ≥70 years), educational level (elementary school graduate or below, middle school graduate, high school graduate, and college graduate or higher), marital status (single, once married, and married), income status (low, mid-low, mid-high, and high), job (white collar, pink collar, blue collar, and unemployed), smoking (current, former, and never), alcohol intake (yes or no), BMI (average, overweight, and obese), diabetes (yes or no), daily calorie intake (less than recommended, recommended, and more than recommended), and family history of chronic diseases (yes or no). The subjects were classified into 3 groups by BMI—average (<23 kg/m^2), overweight (23–24.9 kg/m^2), and obese (≥25 kg/m^2)—according to the WHO criteria for adults.[23 24] The subjects were also classified into 3 groups by daily caloric intake—less than recommended, recommended, and more than recommended—in alignment with the criteria of the National Research Council in the USA.[25]

Statistical analysis

The general characteristics of the study subjects were analyzed using t-test and analysis of variance with regard to comparisons of the differences in median HOMA2-IR. The HOMA2-IR values were log transformed for parametric tests. A multiple regression analysis was used to analyze the associations between the HOMA2-IR and the type and frequency of PA. Additionally, a sex-stratified analysis was performed to determine whether different patterns exist between men and women. Statistical analyses were conducted using the SAS software, V.9.4 (SAS Institute). All p values in this study were two sided and considered significant at <0.05.

RESULTS

The 2015 baseline general characteristics of the study subjects are shown in table 1 according to sex, along with the relationship between HOMA2-IR and each of the covariates. The 1645 male subjects reported the following: 153 (9.3%), no activity; 180 (10.9%), walking <5 times per week; 179 (10.9%), walking ≥5 times per week; 65 (4.0%), MVPA <5 times per week; 83 (5.0%), MVPA ≥5 times

Table 1 General characteristics of the study population at the 2015 baseline

	Men					Women				
	Subjects		HOMA2-IR			Subjects		HOMA2-IR		
Variables	n	%	Median	IQR	P value	n	%	Median	IQR	P value
Total	1645	100	0.874	0.574–1.333		2272	100	0.845	0.584–1.263	
Type and frequency of PA					0.0729					0.0062
No activity	153	9.3	1.015	0.601–1.477		200	8.8	0.927	0.572–1.363	
Walking+ <5 times	180	10.9	0.917	0.607–1.456		320	14.1	0.932	0.627–1.425	
Walking+ ≥5 times	179	10.9	0.933	0.569–1.403		295	13	0.834	0.611–1.311	
MVPA*+ <5 times	65	4	0.913	0.649–1.447		98	4.3	0.826	0.5–1.222	
MVPA+ ≥5 times	83	5	0.799	0.551–1.244		73	3.2	0.922	0.577–1.346	
Walking and MVPA+ <5 times	258	15.7	0.89	0.601–1.276		374	16.5	0.845	0.565–1.211	
Walking and MVPA+ ≥5 times	727	44.2	0.835	0.559–1.261		912	40.1	0.814	0.583–1.205	
Age					0.0014					<0.0001
19–29	243	14.8	0.913	0.64–1.395		270	11.9	0.862	0.662–1.256	
30–39	208	12.6	0.909	0.632–1.437		365	16.1	0.779	0.551–1.131	
40–49	274	16.7	0.897	0.608–1.357		450	19.8	0.775	0.546–1.156	
50–59	343	20.9	0.874	0.576–1.311		503	22.1	0.845	0.577–1.235	
60–69	331	20.1	0.829	0.519–1.279		375	16.5	0.908	0.616–1.34	
≥70	246	15	0.774	0.509–1.348		309	13.6	0.956	0.64–1.508	
Educational level					<0.0001					<0.0001
Elementary school graduate/below	211	12.8	0.757	0.461–1.304		485	21.3	0.97	0.633–1.497	
Middle school graduate	183	11.1	0.752	0.502–1.34		264	11.6	0.883	0.607–1.347	
High school graduate	453	27.5	0.862	0.565–1.304		652	28.7	0.842	0.581–1.226	
College graduate/higher	798	48.5	0.925	0.631–1.37		871	38.3	0.789	0.573–1.144	
Marital status					0.023					0.0058
Single	334	20.3	0.9	0.639–1.403		311	13.7	0.826	0.63–1.22	
Once married	116	7.1	0.799	0.506–1.307		414	18.2	0.912	0.586–1.381	
Married	1195	72.6	0.867	0.565–1.318		1547	68.1	0.835	0.575–1.23	
Income status					0.3218					0.0001
Low	363	22.1	0.834	0.528–1.364		520	22.9	0.923	0.63–1.386	
Mid-low	395	24	0.867	0.564–1.3		575	25.3	0.847	0.588–1.25	
Mid-high	420	25.5	0.898	0.597–1.352		599	26.4	0.833	0.577–1.261	
High	424	25.8	0.882	0.573–1.273		578	25.4	0.782	0.565–1.152	
Job					0.0237					<0.0001
White collar	456	27.7	0.929	0.623–1.398		478	21	0.79	0.573–1.156	
Pink collar	175	10.6	0.855	0.605–1.244		344	15.1	0.863	0.644–1.238	
Blue collar	562	34.2	0.808	0.545–1.272		358	15.8	0.816	0.552–1.193	

Continued

Table 1 Continued

	Men					Women				
	Subjects		HOMA2-IR			Subjects		HOMA2-IR		
Variables	n	%	Median	IQR	P value	n	%	Median	IQR	P value
Unemployed	452	27.5	0.904	0.569–1.424		1092	48.1	0.887	0.59–1.345	
Smoking					0.6875					0.0103
Current	524	31.9	0.871	0.566–1.346		93	4.1	1.011	0.643–1.546	
Former	738	44.9	0.9	0.601–1.335		122	5.4	0.865	0.599–1.245	
Never	383	23.3	0.838	0.552–1.314		2057	90.5	0.84	0.583–1.256	
Alcohol					0.01					0.0011
Yes	1569	95.4	0.869	0.573–1.321		1892	83.3	0.829	0.583–1.238	
No	76	4.6	0.935	0.623–1.586		380	16.7	0.923	0.61–1.421	
BMI					<0.0001					<0.0001
Average	563	34.2	0.613	0.431–0.861		1100	48.4	0.674	0.491–0.943	
Overweight	450	27.4	0.83	0.591–1.185		488	21.5	0.92	0.649–1.295	
Obese	632	38.4	1.263	0.888–1.813		684	30.1	1.215	0.841–1.757	
Diabetes					<0.0001					<0.0001
Yes	163	9.9	1.086	0.658–1.709		146	6.4	1.22	0.858–1.799	
No	1482	90.1	0.858	0.57–1.3		2126	93.6	0.824	0.578–1.224	
Daily calorie intake					0.0984					0.0047
Less than recommended	846	51.4	0.888	0.57–1.374		1475	64.9	0.858	0.599–1.285	
Recommended	370	22.5	0.803	0.54–1.256		289	12.7	0.854	0.585–1.263	
Higher than recommended	429	26.1	0.907	0.629–1.339		508	22.4	0.788	0.559–1.184	
Family history of chronic diseases					0.015					0.0034
Yes	271	16.5	0.982	0.616–1.412		401	17.6	0.893	0.63–1.395	
No	1374	83.5	0.862	0.567–1.318		1819	80.1	0.834	0.58–1.236	

*Moderate-to-vigorous physical activity (MVPA) includes vigorous intensity, moderate intensity, strength and flexibility exercise.
BMI, body mass index; HOMA2-IR, homeostatic model assessment of insulin resistance; PA, physical activity.

Table 2 Results of analyzing the effect of the type and frequency of exercise

	HOMA2-IR (log transformed)					
	Men			Women		
Variables	β	SE	P value	β	SE	P value
Type and frequency of PA						
No activity	Ref			Ref		
Walking+ <5 times	−0.023	0.078	0.7695	−0.027	0.061	0.652
Walking+ ≥5 times	−0.029	0.084	0.7268	0.029	0.057	0.6105
MVPA*+ <5 times	−0.099	0.094	0.296	0.013	0.071	0.8497
MVPA+ ≥5 times	−0.214	0.091	0.0198	−0.128	0.08	0.1104
Walking and MVPA+ <5 times	−0.073	0.068	0.2797	−0.006	0.057	0.9224
Walking and MVPA+ ≥5 times	−0.183	0.064	0.0049	−0.071	0.047	0.1346
Age						
19–29	Ref			Ref		
30–39	−0.126	0.086	0.1457	−0.158	0.065	0.0159
40–49	−0.178	0.084	0.0367	−0.233	0.064	0.0004
50–59	−0.229	0.09	0.0113	−0.206	0.067	0.0026
60–69	−0.285	0.097	0.0037	−0.202	0.079	0.0117
≥70	−0.191	0.101	0.059	−0.206	0.088	0.0201
Educational level						
Elementary school graduate/below	Ref			Ref		
Middle school graduate	0.058	0.085	0.5006	−0.051	0.053	0.3423
High school graduate	0.08	0.078	0.3072	−0.036	0.049	0.4668
College graduate/higher	0.122	0.091	0.1811	−0.028	0.054	0.6089
Marital status						
Single	0.032	0.075	0.6728	0.041	0.059	0.487
Once married	0.008	0.081	0.9239	−0.005	0.047	0.9164
Married	Ref			Ref		
Income status						
Low	Ref			Ref		
Mid-low	−0.029	0.049	0.5572	−0.017	0.042	0.6882
Mid-high	−0.004	0.053	0.9395	−0.037	0.035	0.2908
High	0.004	0.05	0.9321	−0.058	0.036	0.1127
Job						
White collar	Ref			Ref		
Pink collar	−0.052	0.051	0.3126	0.067	0.041	0.1033
Blue collar	−0.037	0.048	0.4402	−0.045	0.051	0.3725
Unemployed	0.019	0.047	0.6835	0.076	0.033	0.0221
Smoking						
Current	0.065	0.037	0.0808	−0.138	0.086	0.1091
Former	0.043	0.044	0.3221	−0.095	0.062	0.1286
Never	Ref			Ref		
Alcohol						
Yes	Ref			Ref		
No	0.086	0.084	0.3047	0.033	0.042	0.4308
BMI						
Average	Ref			Ref		
Overweight	0.323	0.041	<0.0001	0.328	0.033	<0.0001
Obese	0.763	0.038	<0.0001	0.662	0.031	<0.0001
Diabetes						
Yes	0.304	0.06	<0.0001	0.318	0.062	<0.0001
No	Ref			Ref		
Daily calorie intake						
Less than recommended	0.052	0.04	0.202	−0.007	0.036	0.851
Recommended	Ref			Ref		
More than recommended	0.027	0.041	0.5054	−0.05	0.042	0.2341

Continued

Table 2 Continued

	HOMA2-IR (log transformed)					
	Men			Women		
Variables	β	SE	P value	β	SE	P value
Family history of chronic diseases						
Yes	0.039	0.043	0.3608	0.08	0.036	0.0283
No	Ref			Ref		

*Moderate -to-vigorous physical activity (MVPA) includes vigorous intensity, moderate intensity, strength and flexibility exercise.
BMI, body mass index; HOMA2-IR, homeostatic model assessment of insulin resistance; MVPA, moderate-to-vigorous physical activity; PA, physical activity.

per week; 258 (15.7%), walking plus MVPA <5 times per week; and 727 (44.2%), walking plus MVPA ≥5 times per week. The corresponding median (IQR) HOMA2-IR scores were 1.015 (0.601–1.477), 0.917 (0.607–1.456), 0.933 (0.569–1.403), 0.913 (0.649–1.447), 0.799 (0.551–1.244), 0.890 (0.601–1.276) and 0.835 (0.559–1.261), respectively. The 2272 female subjects reported the following: 200 (8.8%), no activity; 320 (14.1%), walking <5 times per week; 295 (13.0%), walking ≥5 times per week; 98 (4.3%), MVPA <5 times per week; 73 (3.2%), MVPA ≥5 times per week; 374 (16.5%), walking plus MVPA <5 times per week; and 912 (40.1%), walking plus MVPA ≥5 times per week. The corresponding median (IQR) HOMA2-IR scores were 0.927 (0.572–1.363), 0.932 (0.627–1.425), 0.834 (0.611–1.311), 0.826 (0.500–1.222), 0.922 (0.577–1.346), 0.845 (0.565–1.211) and 0.814 (0.583–1.205), respectively. In addition, the dependent variable of this study, HOMA2-IR, was calculated by levels of triglyceride (TG) and high-density lipoprotein cholesterol (HDL-C). The results of the regression analysis revealed that among men, both TG (β: 0.07, p≤0.0001) and HDL-C (β: −0.90, p≤0.0001) are associated with IR with statistical significance. Among women, both TG (β: 0.18, p≤0.0001) and HDL-C (β: −0.64, p≤0.0001) again showed a statistically significant relationship with IR.

Table 2 describes the relationships of HOMA2-IR with the combined type plus frequency. Among men, the log HOMA2-IR decreased when individuals performed MVPA ≥5 times per week (β: −0.214, p≤0.0198) and walking plus MVPA ≥5 times per week (β: −0.183, p≤0.0049). No statistically significant results were observed among women. Regarding BMI, both men with overweight (β: 0.323, p≤0.0001) and obese BMI (β: 0.763, p≤0.0001) exhibited increased log HOMA2-IR values than men with average BMI. Women with overweight (β: 0.328, p≤0.0001) and obese BMI (β: 0.662, p≤0.0001) also exhibited increased log HOMA2-IR values than women with average BMI. When diabetes was considered, statistically significant results were observed in both men (β: 0.304, p≤0.0001) and women (β: 0.318, p≤0.0001) with regard to HOMA2-IR.

Table 3 presents the associations between PA and the log HOMA2-IR by BMI and daily calorie intake. Men with an overweight BMI generally exhibited significant results with respect to the combined type plus frequency of PA. When the PA type and frequency were evaluated concurrently, the highest scores were obtained in the group that reported walking plus MVPA ≥5 times per week (β: −0.425, p≤0.0006), followed by those who performed walking ≥5 times per week (β: −0.376, p≤0.0105), MVPA ≥5 times per week (β: −0.368, p≤0.0318) group, walking plus MVPA <5 times per week (β: −0.310, p≤0.0334), and walking <5 times per week (β: −0.243, p≤0.0385). Men with an obese BMI also exhibited significant associations of HOMA2-IR with PA type plus frequency, but only in the MVPA ≥5 times per week (β: −0.294, p≤0.0250) group. Among women, by contrast, statistically significant results were only observed among those with an average BMI who reported walking plus MVPA ≥5 times per week (β: −0.135, p≤0.0238).

We further observed that men who consumed more than the recommended daily calorie intake exhibited significant associations in the analysis. Highest scores were found in those in the walking plus MVPA ≥5 times per week (β: −0.269, p≤0.0468) group, followed by the walking plus MVPA ≥5 times per week (β: −0.350, p≤0.0030) group. Among women, no significant results were found.

DISCUSSION

This study analyzed the associations of the HOMA2-IR with the type and frequency of leisure-time PA using data from a nationally representative sample of Korean adults. The results revealed that in men, the combined type and frequency of PA correlate with negative changes in HOMA2-IR. Specifically, the performance of MVPA ≥5 times per week and walking plus MVPA ≥5 times per week reduced HOMA2-IR levels.

In the subgroup analysis, significant associations were found between HOMA2-IR and the combined type and frequency of PA among men with overweight BMI. Specifically, HOMA2-IR was most reduced by walking plus MVPA ≥5 times per week, followed by walking ≥5 times per week and MVPA ≥5 times per week. Among men with obese BMI, the performance of MVPA ≥5 times per week group had reduced HOMA2-IR level. In addition, among men who consumed more than the recommended daily calorie intake, walking plus MVPA ≥5 times per week most effectively reduced HOMA2-IR, followed by MVPA ≥5 times per week. By contrast, only 1 variable, walking plus MVPA ≥5 times, affected HOMA2-IR of women in the average BMI group.

Our study results are consistent with those of previous studies, in which participation in overall and vigorous PA was found to associate with significantly high insulin sensitivity.[19] Additionally, in a prospective cohort study examining the association between regular vigorous exercise and the subsequent incidence of non-insulin-dependent diabetes mellitus, PA was identified as a probable preventive method.[12] Another

Table 3 Subgroup analysis of physical activity with HOMA2-IR

	HOMA-2IR (log transformed)																	
	BMI									Daily calorie intake								
	Average			Overweight			Obese			Less than recommended			Recommended			More than recommended		
Variables	β	SE	P value	β	SE	P value	β	SE	P value	β	SE	P value	β	SE	P value	β	SE	P value
Men																		
Type and frequency																		
No activity	Ref			Ref			Ref			Ref			Ref			Ref		
Walking+ <5 times	0.027	0.136	0.8413	−0.243	0.116	0.0385	0.061	0.106	0.5673	−0.022	0.101	0.826	0.066	0.147	0.6536	−0.152	0.148	0.306
Walking+ ≥5 times	0.072	0.143	0.6132	−0.376	0.145	0.0105	0.074	0.118	0.5311	0.015	0.098	0.8747	−0.262	0.141	0.0647	0.016	0.166	0.9218
MVPA*+ <5 times	0.15	0.182	0.4109	−0.315	0.182	0.0847	−0.117	0.103	0.2569	0.043	0.132	0.7433	−0.189	0.186	0.3106	−0.246	0.164	0.1361
MVPA+ ≥5 times	−0.01	0.156	0.9471	−0.368	0.17	0.0318	−0.294	0.13	0.025	−0.232	0.126	0.0678	−0.203	0.201	0.3147	−0.269	0.134	0.0468
Walking and MVPA+ <5 times	−0.081	0.118	0.4973	−0.31	0.144	0.0334	0.036	0.094	0.7047	−0.01	0.092	0.9109	−0.213	0.139	0.1265	−0.164	0.133	0.2187
Walking and MVPA+ ≥5 times	−0.067	0.117	0.5703	−0.425	0.121	0.0006	−0.116	0.082	0.1617	−0.115	0.082	0.1612	−0.189	0.14	0.1798	−0.35	0.116	0.003
Women																		
Type and frequency																		
No activity	Ref			Ref			Ref			Ref			Ref			Ref		
Walking+ <5 times	−0.126	0.081	0.1193	0.123	0.13	0.3448	0.027	0.108	0.8027	0	0.074	0.9997	0.001	0.145	0.9918	−0.111	0.11	0.3133
Walking+ ≥5 times	0.064	0.082	0.4336	−0.127	0.136	0.3523	0.059	0.096	0.5394	0.11	0.075	0.1468	−0.16	0.144	0.2689	−0.082	0.103	0.4266
MVPA+ <5 times	0.04	0.09	0.6593	−0.285	0.18	0.1153	0.133	0.111	0.2314	0.028	0.086	0.7483	0.076	0.179	0.6711	−0.072	0.134	0.5952
MVPA+ ≥5 times	−0.213	0.123	0.0862	0.024	0.207	0.9068	−0.061	0.11	0.5811	−0.092	0.097	0.3447	−0.071	0.199	0.7221	−0.288	0.161	0.0757
Walking and MVPA+ <5 times	−0.092	0.071	0.2006	0.108	0.135	0.4264	0.006	0.097	0.9495	0.037	0.07	0.5962	0.031	0.171	0.8573	−0.159	0.102	0.1227
Walking and MVPA+ ≥5 times	−0.135	0.059	0.0238	0.027	0.116	0.8169	−0.059	0.085	0.4896	−0.043	0.062	0.487	−0.108	0.134	0.4198	−0.11	0.093	0.2369

*Moderate-to-vigorous physical activity (MVPA) includes vigorous intensity, moderate intensity, strength and flexibility exercise.
BMI, body mass index; HOMA2-IR, homeostatic model assessment of insulin resistance.

study also found that MVPA affects the prevention of type 2 diabetes.[26]

One particular focus of this study was the potential influence of walking, one of the lightest and most basic physical activities, on IR, given that this form of exercise has been identified as one of the most effective in terms of a wide range of health benefits.[27 28] Notably, previous studies have reported that walking may reduce the incidence of premature death,[29] chronic disease,[27] while brisk walking was shown to improve insulin sensitivity.[26] Moreover, another study found that low-intensity exercise, including walking, effectively reduces HOMA-IR; however, the study focused solely on patients with diabetes and their treatment, with variables including other types of low-intensity PA and hospital diet.[30] As previous studies of walking have yielded various results, further investigation is needed to clarify the associations between various walking strengths and HOMA-IR.

In this study, MVPA ≥5 times per week was associated with the lowest HOMA2-IR levels, followed by walking plus MVPA ≥5 times per week; by contrast, generally walking alone did not affect HOMA2-IR. A statistically significant result was found only in men with overweight BMI. Although these results are consistent with those of previous studies reporting steady exercise as an effective means of reducing IR,[19] they also present MVPA, rather than walking, as an associative factor with HOMA-IR. However, among subjects with a particularly high (ie, overweight) BMI, walking was also associated with a lower HOMA2-IR. In general, although walking is known to be beneficial to health,[27 28] it generally did not improve IR in this study.

Our results allow us to suggest the most effective PA type and frequency for reducing HOMA2-IR, and to make particularly specific inferences and recommendations for individuals with an overweight BMI. Appropriate PA is known to have various beneficial health effects, and certain PAs affect the HOMA2-IR. Therefore, a reduction in the HOMA2-IR could be better achieved by exercising the most appropriate type and frequency of PA according to the subject's individual characteristics. However, we note that statistically significant associations were only observed among male subjects in this study and further studies are needed to investigate relevant associations among women. In conclusion, the findings of this study suggest that PA is negatively associated with the HOMA2-IR.

This research had some limitations. For example, the PA type and frequency categories were not stratified into more detailed subcategories. With respect to PA type, this study aimed to investigate whether walking alone could reduce IR; therefore, all the exercises except walking were combined into a single group. In addition, we attempted to investigate the duration and other frequently used variables for a more detailed classification of PA, such as information on heart rate, oxygen uptake. Due to data limitations, however, the correlation of HOMA2-IR with such variables could not be determined. Moreover, this study featured a cross-sectional design; therefore, we could not exclude a potential bidirectional effect.

CONCLUSION

Among Korean adults, and especially among men, participating in MVPA was associated with a reduction in the HOMA2-IR, regardless whether walking was practiced. Additionally, among men with an overweight BMI and those who consumed above the recommended daily calorie intake, walking plus MVPA ≥5 times per week appeared to be most effective for reducing the HOMA2-IR. These findings infer the potential benefits of performing PA in a manner that could effectively reduce the HOMA2-IR.

Contributors JK and ECP designed the study, collected the data, performed the statistical analysis, and drafted the manuscript. JK, ECP, WK, SAL, and DC contributed to the discussion and reviewed and edited the manuscript. ECP is the guarantor of this work, and as such had full access to all study data. ECP assumes responsibility for the integrity of the data and the accuracy of the data analysis.

Funding The authors have not declared a specific grant for this research from any funding agency in the public, commercial or not-for-profit sectors.

Competing interests None declared.

Patient consent for publication Not required.

Provenance and peer review Not commissioned; externally peer reviewed.

REFERENCES

1 World Health Organization. *Global report on diabetes: World Health Organization*, 2016.
2 Roglic G. WHO Global report on diabetes: A summary. *Int J Noncommun Dis* 2016;1:3.
3 Lillioja S, Mott DM, Spraul M, *et al*. Insulin resistance and insulin secretory dysfunction as precursors of non-insulin-dependent diabetes mellitus. Prospective studies of Pima Indians. *N Engl J Med* 1993;329:1988–92.
4 Martin BC, Warram JH, Krolewski AS, *et al*. Role of glucose and insulin resistance in development of type 2 diabetes mellitus: results of a 25-year follow-up study. *Lancet* 1992;340:925–9.
5 Reaven GM. Role of insulin resistance in human disease. *Diabetes* 1988;37:1595–607.
6 DeFronzo RA, Tobin JD, Andres R. Glucose clamp technique: a method for quantifying insulin secretion and resistance. *Am J Physiol* 1979;237:E214.
7 Morris AD, Ueda S, Petrie JR, *et al*. The euglycaemic hyperinsulinaemic clamp: an evaluation of current methodology. *Clin Exp Pharmacol Physiol* 1997;24:513–8.
8 Lorenzo C, Haffner SM, Stančáková A, *et al*. Fasting and OGTT-derived measures of insulin resistance as compared with the euglycemic-hyperinsulinemic clamp in nondiabetic Finnish offspring of type 2 diabetic individuals. *J Clin Endocrinol Metab* 2015;100:544–50.
9 Bonora E, Targher G, Alberiche M, *et al*. Homeostasis model assessment closely mirrors the glucose clamp technique in the assessment of insulin sensitivity: studies in subjects with various degrees of glucose tolerance and insulin sensitivity. *Diabetes Care* 2000;23:57–63.
10 Kahn BB, Flier JS. Obesity and insulin resistance. *J Clin Invest* 2000;106:473–81.
11 Westphal SA, Obesity WSA. Obesity, abdominal obesity, and insulin resistance. *Clin Cornerstone* 2008;9:23–31.
12 Manson JE, Rimm EB, Stampfer MJ, *et al*. Physical activity and incidence of non-insulin-dependent diabetes mellitus in women. *Lancet* 1991;338:774–8.
13 Eriksson KF, Lindgärde F. Prevention of type 2 (non-insulin-dependent) diabetes mellitus by diet and physical exercise. The 6-year Malmö feasibility study. *Diabetologia* 1991;34:891–8.
14 Ewing R, Meakins G, Hamidi S, *et al*. Relationship between urban sprawl and physical activity, obesity, and morbidity - update and refinement. *Health Place* 2014;26:118–26.
15 Haapanen N, Miilunpalo S, Pasanen M, *et al*. Association between leisure time physical activity and 10-year body mass change among working-aged men and women. *Int J Obes Relat Metab Disord* 1997;21:288–96.
16 Manson JE, Hu FB, Rich-Edwards JW, *et al*. A prospective study of walking as compared with vigorous exercise in the prevention of coronary heart disease in women. *N Engl J Med* 1999;341:650–8.
17 Dosemeci M, Hayes RB, Vetter R, *et al*. Occupational physical activity, socioeconomic status, and risks of 15 cancer sites in Turkey. *Cancer Causes Control* 1993;4:313–21.
18 Holmes MD, Chen WY, Feskanich D, *et al*. Physical activity and survival after breast cancer diagnosis. *JAMA* 2005;293:2479–86.

19 Mayer-Davis EJ, D'Agostino R, Karter AJ, *et al*. Intensity and amount of physical activity in relation to insulin sensitivity: the Insulin Resistance Atherosclerosis Study. *JAMA* 1998;279:669–74.
20 Frayn KN. Visceral fat and insulin resistance–causative or correlative? *Br J Nutr* 2000;83 Suppl 1(S1):S71–S7.
21 Matthews DR, Hosker JP, Rudenski AS, *et al*. Homeostasis model assessment: insulin resistance and beta-cell function from fasting plasma glucose and insulin concentrations in man. *Diabetologia* 1985;28:412–9.
22 Levy JC, Matthews DR, Hermans MP. Correct homeostasis model assessment (HOMA) evaluation uses the computer program. *Diabetes Care* 1998;21:2191–2.
23 World Health Organization. *Obesity: preventing and managing the global epidemic: World Health Organization*, 2000.
24 WHO Expert Consultation. Appropriate body-mass index for Asian populations and its implications for policy and intervention strategies. *Lancet* 2004;363:157–63.
25 Council NR. *Recommended Dietary Allowances*. 10 edn. Washington, DC: The National Academies Press, 1989:302.
26 Ekelund U, Brage S, Griffin SJ, *et al*. Objectively measured moderate- and vigorous-intensity physical activity but not sedentary time predicts insulin resistance in high-risk individuals. *Diabetes Care* 2009;32:1081–6.
27 Lee IM, Buchner DM. The importance of walking to public health. *Med Sci Sports Exerc* 2008;40:S512–S518.
28 Hanson S, Jones A. Is there evidence that walking groups have health benefits? A systematic review and meta-analysis. *Br J Sports Med* 2015;49:710–5.
29 Warburton DE, Nicol CW, Bredin SS. Health benefits of physical activity: the evidence. *CMAJ* 2006;174:801–9.
30 Kishimoto H, Taniguchi A, Fukushima M, *et al*. Effect of short-term low-intensity exercise on insulin sensitivity, insulin secretion, and glucose and lipid metabolism in non-obese Japanese type 2 diabetic patients. *Horm Metab Res* 2002;34:27–31.