



Sex differences in the change of exercise behavior leading to incident metabolic syndrome reduction: A community-based prospective study

Hsiu-Fan Hsu^a, Yen-Po Yeh^b, Tony Hsiu-Hsi Chen^c, Dih-Ling Luh^{a,d,*}

^a Department of Public Health, Chung Shan Medical University, Taichung 402, Taiwan, ROC

^b Changhua County Public Health Bureau, Changhua 500, Taiwan, ROC

^c Institute of Epidemiology and Preventive Medicine, College of Public Health, National Taiwan University, Room 533, Taipei 100, Taiwan, ROC

^d Department of Family and Community Medicine, Chung Shan Medical University Hospital, Taichung 402, Taiwan, ROC

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ABSTRACT

This study was undertaken to assess the role of sex differences in the effects of exercise behavior change on incident metabolic syndrome (MetS) in Changhua County, Taiwan. Using data derived from the Changhua Community-based Integrated Screening (CHCIS), 22,594 eligible residents aged 40 years or older had the screening at least twice from 2005 to 2018. A prospective cohort study was designed to follow up the normal cohort without MetS at baseline to ascertain incident MetS in the light of the criteria of the Epidemiology Task Force Consensus Group. We then evaluated whether there was a sex difference in the outcome of incident MetS attributed to the change in exercise behavior from three (no, irregular, and regular exercise) maintained patterns already defined at baseline to either the enhanced pattern or the reduced pattern by the end of follow-up. We applied Cox proportional hazards regression model stratified by sex for estimating the hazard ratio of any two-group comparison. After adjustment for sociodemographic factors, the number of screenings attended, personal disease history, and other health behaviors, the influence of change in exercise behavior on incident MetS was statistically significant only in men. Specifically, maintaining no exercise showed a lower risk of MetS than maintaining regular exercise 21 % in men. Regarding the change in exercise behavior, men with the enhanced pattern reduced the risk of MetS by 15 % compared with those maintaining regular exercise. The findings suggest that positive changes in exercise behavior reduce the incidence of MetS in men but not in women.

1. Introduction

Physical activity (PA) is recognized as an effective strategy to promote health (Rhodes et al., 2017), prevent non-communicable diseases (NCDs) (World Health Organization, 2013; Waxman, 2004), and decrease premature mortality (Rhodes et al., 2017), and metabolic syndrome (MetS) is one of the NCDs that has been proven to be preventable with PA (Myers et al., 2019; Rhodes et al., 2017). MetS is not only an important precursor to NCDs (Samson and Garber, 2014) but also a cost-effective preventable health condition (Joshi et al., 2020) currently affecting over one billion people worldwide (Saklayen, 2018).

The benefits of PA for MetS include the impact of exercise on insulin resistance, adipose fuel metabolism, inflammation, and epigenetic factors (Myers et al., 2019). Furthermore, longitudinal observational studies, randomized controlled trials, and meta-analysis studies have shown that PA can prevent MetS in the general population and prevent

related diseases in MetS patients (Myers et al., 2019). Although only a few studies showed a statistically insignificant correlation between PA and the incidence of MetS (Santos et al., 2010), there is some limited empirical evidence on the relationship between natural changes in PA and MetS occurrence.

In particular, sex is a critical factor to explore in the relationship between changes in PA and MetS occurrence because of (1) sex differences in the incidence of MetS (Hadaegh et al., 2013; Hwang et al., 2013), (2) sex differences in PA behavior (Hallal et al., 2012; Mao et al., 2020), and (3) the possible moderation effects of sex on the relationship between PA and MetS (Chang et al., 2019). It is reasonable to hypothesize that there are sex differences in the association between exercise habits and the development of MetS. Therefore, using data from the Changhua Community-based Integrated Screening (CHCIS), this study investigates the relationship between changes in exercise behavior and the incidence of MetS with a view toward sex stratification.

* Corresponding author at: Department of Public Health, Chung Shan Medical University, 110 Sec. 1 Chien-Kuo N. Rd., Taichung 40201, Taiwan, ROC
E-mail address: luh@csmu.edu.tw (D.-L. Luh).

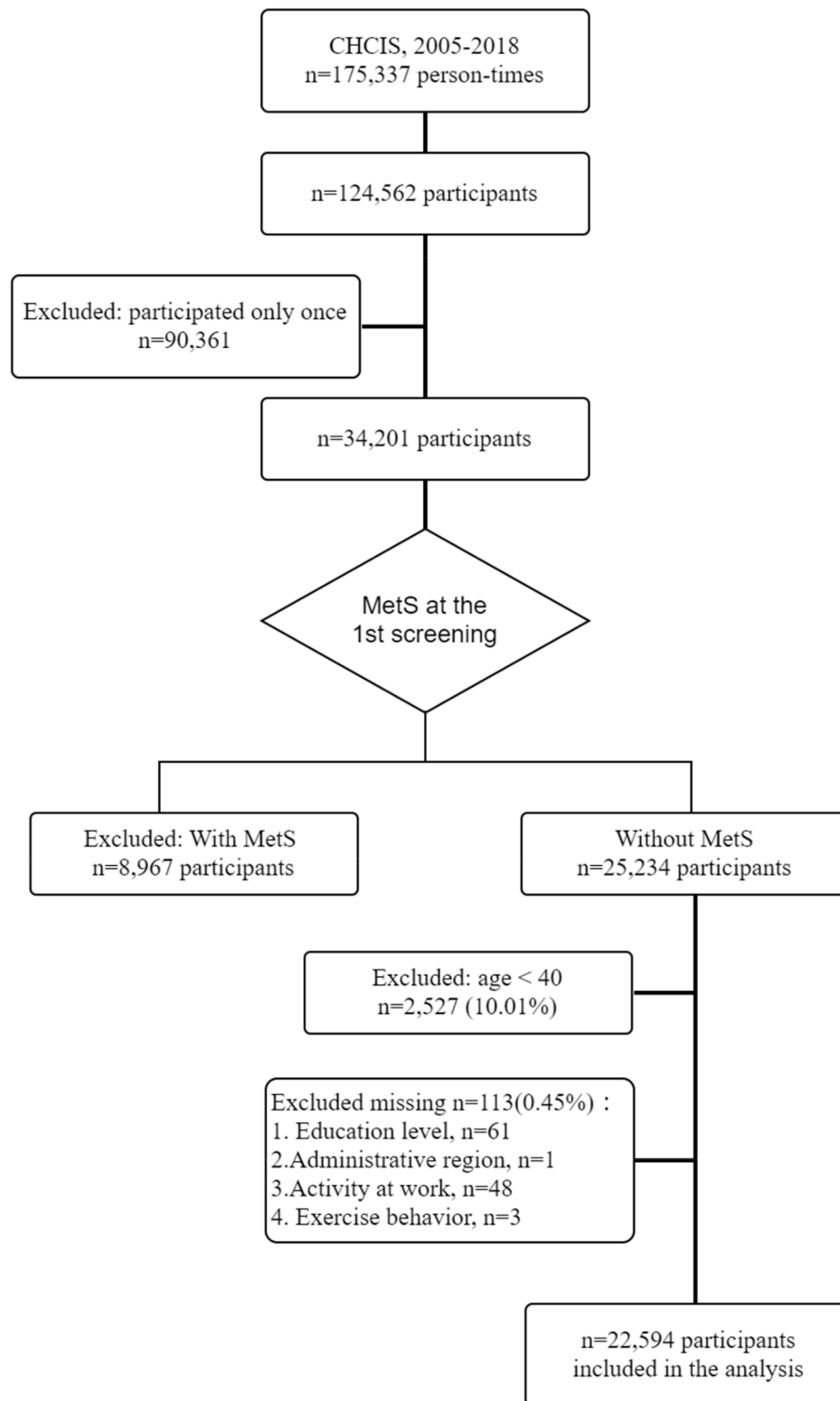


Fig. 1. Flow chart for the study population.

2. Methods

2.1. Participants

The CHCIS, offered by the Changhua Health Bureau, offers multi-disease screening for people over 30 years of age. The screening modality of CHCIS originated in Keelung City and was referenced from a previous study published elsewhere (Chen et al. 2004). CHCIS commenced in 2005 and is administered annually, providing screening

for multiple cancers (liver, breast, colorectal, oral, and cervical) and chronic diseases (hyperlipidemia, hypertension, hyperglycemia, and MetS), biochemical tests (blood and urine samples), and anthropometric measurements (height, weight, and circumference of the waist and hips) (Yeh et al., 2014). In addition, a structured questionnaire is used to understand participants' health-related lifestyles (exercise, smoking, drinking alcohol, chewing betel nuts, dietary intake) and personal and family disease histories.

Data were drawn from the CHCIS screening database for the years

2005 to 2018, which contains 175,337 person-times records belonging to 124,562 participants. To delineate the incidence of MetS, we included the participants who were screened at least twice (n = 34,201) and did not have MetS at the first screening (n = 25,234). The exclusion criteria were as follows: (1) aged <40 years (n = 2,527) or records with missing data (n = 113). (Fig. 1).

2.2. Definition of variables

2.2.1. Outcome variable: Incidence of MetS

This study used the definition of MetS by the Epidemiology Task Force Consensus Group (Alberti et al., 2005), which is better suited to Asian populations than the definition provided by the National Cholesterol Education Programme Adult Treatment Panel III (Expert Panel on Detection, 2001). The biochemical results of CHCIS screening indicate that those who meet three or more of the following five criteria are considered to have MetS: (1) central obesity (waist circumference ≥ 80 cm for women and ≥ 90 cm for men), (2) hypertriglyceridemia (≥150 mg/dL), (3) low level of high-density lipoprotein cholesterol (<50 mg/dL for females and < 40 mg/dL for males), (4) elevated blood pressure (systolic blood pressure ≥ 130 mmHg or diastolic blood pressure ≥ 85 mmHg) and (5) hyperglycemia (fasting glucose ≥ 100 mg/dL).

2.2.2. Independent variable: Change in exercise behavior

Taiwan’s official recommendations for exercise behavior (Ministry Of Education, 1999, Sports Administration, Ministry of Education, 2022) classify it into three categories based on self-reported frequency and duration of exercise in the screening questionnaire: none, irregular, or regular. This classification can also be found in the recent literature (Mao et al., 2020). The main question was “Do you exercise currently?” followed by “On average, how many times a week do you exercise” and

“How long do you exercise?” The “regular exercise” group was defined as participants who exercised more than three times a week and for more than 30 min each time. Those who reported that they exercised less than three times per week or <30 min per time were classified into the “irregular exercise” group, and those who did not exercise at all fell into the “no exercise” group.

Then, changes in exercise behavior were identified based on a comparison of exercise behavior at the time MetS occurred and the time of first participation in CHCIS. Changes were classified into five categories: maintain no exercise, maintain irregular exercise, maintain regular exercise, increase, and decrease.

2.2.3. Covariates

- (1) Sociodemographic variables. The sociodemographic covariates were described as follows: Age groups were set by dividing participants between <65 and ≥65 years old, as MetS is more likely to occur in people over 65 years of age (Kuk and Ardern, 2010). Education is divided into four categories: junior high school or below, high school, or college or above. According to the administrative division of Changhua County, the area of residence was divided into city, township, or village. Finally, the degree of PA at work was based on participants’ self-reports, including light, moderate, vigorous, and extreme. In this study, extreme and vigorous were combined into one category because too few participants reported their PA at work as extreme.
- (2) Personal health at the first screening. Personal health includes body mass index (BMI), the number of MetS components, and personal disease history. The BMI was calculated as weight in kilograms divided by the square of height in meters. Based on the Adult Health Status Standard (Health Promotion Administration,

Table 1

Participant characteristics and health-related behaviors at the first screening by sex (n = 22,594).

Variable	n	%	Men		Women		Variable	n	%	Men		Women	
			n	%	n	%				n	%	n	%
Participants	22,594	100.00	7615	33.70	14,979	66.30							
Sociodemographic variables							Health-related behaviors						
Age***							Exercise*						
<65	20,076	88.86	6337	83.22	13,739	91.72	No	9114	40.34	2985	39.20	6129	40.92
≥65	2518	11.14	1278	16.78	1240	8.28	Irregular	6435	28.48	2220	29.15	4215	28.14
Education level***							Regular						
Junior high school or below	13,336	59.02	3907	51.31	9429	62.95	Smoking***	7045	31.18	2410	31.65	4635	30.94
Senior high school	6055	26.80	2265	29.74	3790	25.30	Never	18,496	81.86	3745	49.18	14,751	98.48
College or above	3203	14.18	1443	18.95	1760	11.75	Former	1608	7.12	1540	20.22	68	0.45
Degree of PA at work***							Current						
Light	15,077	66.73	3478	45.67	11,599	77.44	Chewing betel nuts***	2490	11.02	2330	30.60	160	1.07
Moderate	4493	19.89	2404	31.57	2089	13.95	Never	20,699	91.61	5738	75.35	14,961	99.88
Vigorous	3024	13.38	1733	22.76	1291	8.62	Former	1279	5.66	1270	16.68	9	0.06
Living area***							Current						
City	4446	19.68	1252	16.44	3194	21.32	Drinking alcohol***	616	2.73	607	7.97	9	0.06
Township	5395	23.88	1613	21.18	3780	25.24	Never	16,221	71.79	3393	44.56	12,828	85.64
Village	12,756	56.46	4750	62.38	8005	53.44	Former	372	1.65	353	4.64	19	0.13
Personal health							Occasional						
BMI***							Frequent						
BMI < 24	13,051	57.76	3883	50.99	9168	61.21	Dietary habits	4426	19.59	2506	32.91	1920	12.82
24 ≤ BMI < 27	6628	29.34	2764	36.30	3864	25.80	Vegetables≥3 bowls/day	1575	6.97	1363	17.90	212	1.42
BMI≥27	2915	12.90	968	12.71	1947	13.00	Fruit≥7 times/week***	2943	13.03	1005	13.20	1938	12.94
Number of MetS components***							Little beverage***						
0	6556	29.02	1928	25.32	4628	30.90	Little snack*	9194	40.69	2750	36.11	6444	43.02
1	8585	38.00	2978	39.11	5607	37.43		16,184	71.63	4984	65.45	11,200	74.77
2	7453	32.99	2709	35.57	4744	31.67		12,226	54.11	4201	55.17	8025	53.58
Personal disease history													
Diabetes mellitus***	660	2.92	300	3.94	360	2.40							
Hypertension***	2110	9.34	889	11.67	1221	8.15							
Cardiac disease**	669	2.96	263	3.45	406	2.71							
Hyperlipidemia***	606	2.68	251	3.29	355	2.37							

* Indicates the variable showed a statistically significant sex difference by chi-square, * p < 0.05, ** p < 0.01, *** p < 0.001

Table 2
Distribution of screening frequency according to the occurrence of MetS.

	n	%	Observation person-years		MetS							
			mean	SD	No				Yes			
					n	row %	Observation person-years		n	row %	Observation person-years	
							mean	SD			mean	SD
Participants	22,594	100.00	5.27	2.82	17,402	77.02	5.37	2.84	5192	29.84	4.96	2.73
Number of screenings attended												
2	16,618	73.55	4.40	2.38	12,465	75.01	4.41	2.36	4153	24.99	4.39	2.44
3	4181	18.50	7.08	2.33	3419	81.77	7.16	2.28	762	18.23	6.72	2.52
4	1205	5.33	8.89	2.25	1009	83.73	8.95	2.19	196	16.27	8.57	2.54
5	320	1.42	9.41	2.61	267	83.44	9.55	2.54	53	16.56	8.70	2.88
6	135	0.60	9.31	2.51	118	87.41	9.43	2.50	17	12.59	8.43	2.52
7	65	0.29	9.48	2.39	60	92.31	9.57	2.47	5	7.69	8.46	0.51
8	31	0.14	10.39	1.66	29	93.55	10.35	1.71	2	6.45	10.97	0.07
9	17	0.08	11.13	1.85	14	82.35	11.26	1.94	3	17.65	10.54	1.48
10	10	0.04	12.12	0.74	10	100.00	12.12	0.74	0	.	.	.
11	8	0.04	11.11	0.96	7	87.50	11.29	0.88	1	12.50	9.87	.
12	3	0.01	12.51	0.57	3	100.00	12.51	0.57	0	.	.	.
13	1	0.00	12.63	.	1	100.00	12.63	.	0	0.00	.	.

Ministry of Health and Welfare, Taiwan, 2018b), recommended by the Health Promotion Administration in Taiwan, BMI is classified into three groups: <24, 24–27, and ≥27, representing “not overweight,” “overweight,” and “obese,” respectively. The number of MetS components ranged from zero to two (three or higher would be classified as MetS and the participant’s data would be excluded before the analysis). The personal disease history includes diabetes mellitus, hypertension, cardiac disease, and hyperlipidemia, which participants self-reported at the first screening.

- (3) Other health-related behaviors. Therefore, we also included other health-related behaviors in the first screening questionnaire as covariates in the analysis, namely smoking, chewing betel nuts, drinking alcohol, and dietary habits. All behaviors are classified according to their health effects, based on the recommendations of the Ministry of Health and Welfare or the results of previous studies. (i) The classification of smoking behavior and betel nut chewing was based on participants’ self-reports in the screening questionnaire on “Do you smoke/chew betel nut?” (with responses of never, formerly, and currently), as seen in other previous studies (Chang et al., 2006; Katzmarzyk et al., 2005). (ii) The drinking alcohol question was “Do you have any drinking habits?” The responses were divided into four categories: never, previously, occasionally, and frequently. (iii) Dietary habits followed the Taiwan dietary guidelines of the Health Promotion Administration (Health Promotion Administration, Ministry of Health and Welfare, Taiwan, 2018a), including vegetable intake (≥3 bowls/day or not), fruit (≥7 times/week or not), beverages (little or other), and snacks (little or other).

2.3. Statistical analyses

Because this study hypothesized that sex affects the association between changes in exercise behavior and MetS, we first investigated whether there was a significant interaction between sex and exercise behavior change. Exercise behavior change was denoted by category variable (five categories), set to four dummy variables (with continuous exercise as the reference group). Using the Cox regression model (not shown in the results table), after controlling for other significant variables, a significant interaction between sex and change in exercise habits was found: (1) the interaction between sex and persistent physical inactivity showed a statistically significant difference (regression coefficient = 0.28157, p = 0.0016), and (2) the interaction between sex and improvement in exercise behavior was at the margin of significance (regression coefficient = 0.15915, p = 0.0644).

Hence, all analyses were stratified by sex. Cox regression analyses were used to evaluate the associations between changes in exercise behavior and the incidence of MetS after adjustment for possible risk factors for MetS confounders. The person-time was calculated as the observational years between the date of the first screening and the date of MetS identification or the last screening. The 22,594 participants in the study population were observed as 119,150 person-years with a range of observational years of 0.41 to 13.13 (mean = 5.27, SD = 2.82).

The results of Cox regression analyses are presented as hazard ratios (HRs) with 95 % confidence intervals. All statistical tests were conducted in SAS (version 9.4), and p < 0.05 was considered statistically significant.

2.4. Ethical review board

This experimental protocol was conducted with the approval of the Ethical Review Board (Chung Shan Medical University Hospital), approval number CS19019.

3. Results

The distribution of the characteristics and health-related behaviors of the 22,495 participants in the first screening is in Table 1. The majority of the participants are female, younger than 65, educated to the level of secondary school level or below, lightly PA at work, and living in a village. The participants were people without metabolic syndrome at the first screening who were relatively healthy. More than half of the participants had a BMI < 24, and less than one-third did not have any of the MetS components. The rate of chronic disease history (e.g., diabetes, hypertension, heart disease, and hyperlipidemia) was very low. The majority of participants had healthy behaviors: no smoking, no betel nut chewing, no alcohol consumption, and little beverage intake. However, the percentage of regular exercise and adequate amounts of vegetables and fruits were relatively low.

After stratification by sex and chi-square tests, most variables showed significant sex differences, except for vegetable intake. Women were more likely to be younger, lightly active at work, less educated than men were, and more likely to live in cities or towns. Men were more likely to be overweight, have more MetS components, and have chronic diseases. Furthermore, women seemed to have a healthier lifestyle.

Table 2 shows the frequency distribution of screening according to the occurrence of MetS. The overall mean person-years exceeded 5 years and were significantly higher in the group without MetS than in those with MetS (t = 9.36, p < 0.0001, not shown in table). Nearly-three-fourths of the study participants attended only the second screening.

Table 3
Distribution of the occurrence of MetS at the next screening and changes in exercise behavior by sex (n = 22,594).

	Total		Men		Women		χ^2	p
	Total	%	Total	%	Total	%		
Participants	22,594	100	7615	33.7	14,979	66.3		
Yes	5192	22.98	1666	21.88	3526	23.54	7.88	0.005
Change in exercise behavior							24.05 ^c	<0.0001
Maintain regular exercise	4893	21.66	1703	22.36	3190	21.3		
Regular ^a → X ^b → Regular	3395	69.38	1150	67.53	2245	70.38		
Regular → No ^c → Regular	60	1.23	17	1.00	43	1.35		
Regular → Irregular ^d → Regular	178	3.64	62	3.64	116	3.64		
Regular → Regular → Regular	1260	25.75	474	27.83	786	24.64		
Maintain irregular exercise	2691	11.91	987	12.96	1704	11.38		
Irregular → X → Irregular	2005	74.51	741	75.08	1264	74.18		
Irregular → No → Irregular	125	4.65	33	3.34	92	5.40		
Irregular → Irregular → Irregular	407	15.12	164	16.62	243	14.26		
Irregular → Regular → Irregular	154	5.72	49	4.96	105	6.16		
Maintain no exercise	5564	24.63	1889	24.81	3675	24.53		
No → X → No	4358	78.32	1474	78.03	2884	78.48		
No → No → No	938	16.86	325	17.20	613	16.68		
No → Irregular → No	191	3.43	65	3.44	126	3.43		
No → Regular → No	77	1.38	25	1.32	52	1.41		
Increase	5767	25.52	1842	24.19	3925	26.20		
No → X → Irregular	1444	25.04	461	25.03	983	25.04		
No → X → Regular	1128	19.56	341	18.51	787	20.05		
No → No → Irregular	223	3.87	65	3.53	158	4.03		
No → No → Regular	140	2.43	37	2.01	103	2.62		
No → Irregular → Irregular	184	3.19	64	3.47	120	3.06		
No → Irregular → Regular	118	2.05	27	1.47	91	2.32		
No → Regular → Irregular	97	1.68	30	1.63	67	1.71		
No → Regular → Regular	216	3.75	71	3.85	145	3.69		
Irregular → X → Regular	1540	26.70	531	28.83	1009	25.71		
Irregular → NO → Regular	57	0.99	17	0.92	40	1.02		
Irregular → Irregular → Regular	238	4.13	73	3.96	165	4.20		
Irregular → Regular → Regular	382	6.62	125	6.79	257	6.55		
Decrease	3679	16.28	1194	15.68	2485	16.59		
Irregular → X → No	1151	31.29	371	31.07	780	31.39		
Irregular → No → No	162	4.40	55	4.61	107	4.31		
Irregular → Irregular → No	155	4.21	46	3.85	109	4.39		
Irregular → Regular → No	59	1.60	15	1.26	44	1.77		
Regular → X → No	652	17.72	196	16.42	456	18.35		
Regular → X → Irregular	945	25.69	336	28.14	609	24.51		
Regular → No → No	85	2.31	29	2.43	56	2.25		
Regular → No → Irregular	55	1.49	16	1.34	39	1.57		
Regular → Irregular → No	67	1.82	26	2.18	41	1.65		
Regular → Irregular → Irregular	121	3.29	37	3.10	84	3.38		
Regular → Regular → No	72	1.96	16	1.34	56	2.25		
Regular → Regular → Irregular	155	4.21	51	4.27	104	4.19		

Shading presents the exercise behavior at three time points. For those who participated more than four times, the middle exercise behavior is the previous exercise behavior at which MetS occurred, and those who did not occur MetS used the exercise behavior at the penultimate screening time. ^a “regular” was defined as participants who exercised more than three times a week and for more than 30 min each time. ^b For those who participated only twice, there were only two exercise behaviors, so the middle one is shown by “X”. ^c “no” was defined as who did not exercise at all. ^d “Irregular” was defined as participants who exercised less than three times per week or <30 min per time. ^e The chi-square test was a bivariate analysis of change in exercise behavior (five categories: maintain regular exercise, maintain irregular exercise, maintain no exercise, increase decrease,) with sex (men/women).

Table 3 shows the distribution of the incidence of MetS and change in exercise behavior by sex. In this study, the cumulative incidence of MetS was 22.98 % during the 14-year observation period for those without MetS at the first screening.

Table 3 presents not only changes in exercise behavior at two points (the first screening and the screening at which MetS was found/the final screening) but also, in more detail, behavior during the period (the penultimate screening or the one before MetS occurred, which is only available for those who attended more than three screenings). We found that: (1) for the maintained regular exercise group, 4.87 % experienced inactivity or irregular exercise; (2) in the maintained irregular exercise group, 4.65 % had experienced inactivity, and 5.72 % had experienced regular exercise; (3) in the maintained no exercise group, 4.81 % had experienced irregular or regular exercise; (4) in the increasing group, only 2.67 % of exercise behaviors had gotten worse and then better; and (5) in the decreasing group, only 3.09 % of exercise behaviors improved and then become worse. Although a few inconsistencies were seen with the direction of the behavioral change subgroup (around 5 % when

considering three PA measurements), exercise behavior at the first screening visit and at the one at which MetS was observed occurred was used to define behavioral change.

In general, the proportion of change in exercise behavior showed that more than a quarter of people increased their PA, while nearly a quarter remained no exercise, and the smallest group maintained irregular exercise.

Among the 22,594 participants and 119,150 person-years of the 14-year study period (2005–2018), the incidence of MetS was 43.58 per 1,000 person-years (Table 4), without statistically significant sex differences (p = 0.29). Among men, there was a statistically significant association between changes in exercise behavior and the incidence of MetS. Men in the maintain no exercise and the increased exercise groups had a statistically significantly lower risk of MetS than men did in the maintained regular exercise group. On the other hand, among women, there was no statistically significant association between changes in exercise behavior and the incidence of MetS, regardless of the reference group.

Table 4
Relationships between change in exercise behavior and incidence of MetS by Cox regression^a (n = 22,594).

Sex	Incidence of MetS (Per 1,000 person-years)	Incidence of MetS												
		Model 1 ref = maintain regular exercise			Model 2 ref = maintain irregular exercise			Model 3 ref = no exercise			Model 4 ref = increase			
		HR	95 % CI		HR	95 % CI		HR	95 % CI		HR	95 % CI		
Men ^b	43.31 ^c													
Change in exercise behavior														
Maintain regular exercise	48.44	–												
Maintain irregular exercise	38.95	0.93	0.78	1.11	–									
Maintain no exercise	40.07	0.79	0.68	0.92	0.85	0.71	1.02	–						
Increase	42.46	0.85	0.73	0.98	0.91	0.77	1.09	1.07	0.93	1.24	–			
Decrease	46.48	0.91	0.77	1.06	0.98	0.81	1.18	1.15	0.98	1.35	1.07	0.92	1.25	
Women ^b	43.70 ^c													
Change in exercise behavior														
Maintain regular exercise	45.34	–												
Maintain irregular exercise	36.77	0.95	0.84	1.09	–									
Maintain no exercise	46.55	1	0.9	1.11	1.05	0.92	1.19	–						
Increase	41.76	0.94	0.85	1.04	0.98	0.87	1.12	0.94	0.86	1.03	–			
Decrease	45.59	1.01	0.91	1.13	1.06	0.93	1.22	1.02	0.91	1.13	1.08	0.98	1.2	

^a Adjusted for all covariates: age, education, degree of PA at work, living area, BMI, number of screenings attended, number of MetS components, personal disease history, health-related behaviors (smoking, chewing betel nuts, drinking alcohol), and dietary habits (vegetables, fruit, beverages, snacks).

^b In general, there is no statistically significant sex difference (p = 0.29) in the incidence of MetS by multivariate Cox regression model (n = 22,594).

^c Incidence of MetS = number of new cases of MetS/summed person-years of observation.

4. Discussion

The results show an association between changes in exercise behavior and the incidence of MetS only for men, where men who persisted in not exercising or increased their exercise behavior had a lower incidence of MetS than those who maintained regular exercise. These results differ from the findings of previous studies, possibly because (1) PA or exercise behavior can change during the study period, but most previous studies used baseline PA as a predictive variable, and (2) the effect of PA on the incidence of MetS may vary by sex.

4.1. PA or exercise behavior can change during the study period

Though habits are not easily changed (Duhigg, 2012), we found that 42.8 % of the participants' exercise behavior was different from that at the first screening, without intervention. Previous research that used changes in PA or exercise behavior as an independent variable tended to use an interventional design (Mann, 2003) and found that improving PA reduced the incidence of MetS (den Boer et al., 2013; Tran et al., 2017). However, the results of observational studies were inconsistent. Through a longitudinal design, some studies found that physical inactivity at baseline increased the incidence of MetS in Norway (Wilsgaard and Jacobsen, 2007) and Korea (Jo et al., 2020). On the other hand, observational cohort studies showed only insignificant associations between PA and the incidence of MetS in the U.S. (Cheriyath et al., 2010) and Portugal (Santos et al., 2010). All of these studies used baseline PA as a predictive variable and did not consider possible changes in behavior during the study period. One of the strengths of our study was that we delineated the relationships between change in exercise behavior and the incidence of MetS without experimental intervention, and the findings could provide insights into the effect of PA or exercise behavior on MetS that are more detailed.

4.2. The effect of PA on the incidence of MetS may vary by sex

Sex is an important factor in both MetS and PA. There is not only a significant sex difference in the prevalence and incidence of MetS (Hadaegh et al., 2013; Pucci et al., 2017) but also in each of its components (Hwang et al., 2013). In addition, there are sex differences in risk factors for MetS (Scuteri et al., 2009). In terms of exercise behavior, the frequency, intensity, type, or variation has been shown to vary by sex

as well (Althoff et al., 2017; Shaw et al., 2010). Therefore, it is reasonable to hypothesize that sex may influence the relationship between changes in exercise behavior and the incidence of MetS. However, because, to our knowledge, no previous studies have examined the possibility, there are no similar studies to compare our findings.

4.3. Possible reasons for sex differences in the effects of change in exercise behavior on the incidence of MetS

Our study found that men who maintained no exercise and increased exercise were significantly less likely to have MetS. The possible reasons are as follows: (1) A higher proportion of men who maintain no exercise are engaged in more strenuous work than those who maintain regular exercise (73 % for the former and 32 % for the latter, not shown in the table). Therefore, because of the higher total PA (which includes work), the risk of MetS may be lower in men who are physically inactive than in physically active men. A previous study (Mengesha et al., 2019) that used the GPAQ survey found that workplace activities contributed the highest percentage to total PA compared to recreational activities and travel to and from places, and men are more involved in PA at work than women (Hamrik et al., 2014). (2) In addition, we were encouraged to find that those who increased their exercise were significantly less likely to develop MetS than those who maintain regular exercise, but this result was only seen in male participants. Such results not only echo previous intervention studies that increased exercise can prevent the occurrence of chronic diseases (Pedersen and Saltin, 2006) (including MetS (van Namen et al., 2019)) but also provide new evidence that voluntary changes in exercise behavior (without external intervention) can be beneficial in preventing the occurrence of MetS.

However, why did the change in exercise behavior not have a significant effect on the incidence of MetS in women? Possible reasons are that (i) the type and intensity of exercise differ between sexes (Molanorouzi et al., 2015) and (ii) there are sex differences in the mechanisms of exercise effects on MetS. According to Park et al. (2021), regular exercise has no direct effect on the risk of metabolic disease but is mediated by other physiological factors; for instance, body composition (e.g., cell mass, mineral mass, and protein mass) plays an important role for men but obesity-related biomarkers (e.g., body fat) are key factors for women.

4.4. Findings other than the main research purpose

While it was not the main purpose of this study, we estimated the cumulative incidence of MetS by person-years in Changhua County as 43.58 per 1,000 person-years, which was similar to previous studies in other countries (Hadaegh et al., 2013; Santos et al., 2010). This implies there was no significant bias in the integrated screening group in our study.

5. Limitations

The limitations of this study are as follows. The first is related to the measurement and classification of exercise behavior. Exercise behaviors are self-reported in this study, which could lead to measurement errors due to recall bias and social desirability. Self-reported exercise is more likely to focus on high-intensity exercise while ignoring low- to moderate-intensity exercise (Ara et al., 2015). However, self-reported PA questionnaires have been used to estimate PA levels in large cohort studies (Ara et al., 2015); it is a practical assessment in a community-based screening program with implications for public health and the health of the general population. The existing literature also indicates no significant tendency to overestimate or underestimate PA in self-reporting compared to measurement methods (Prince et al., 2008). The PA questions in this study are similar to items in the Behavioral Risk Factor Surveillance System (BRFSS), and past studies have indicated the reliability and validity of PA measurements in BRFSS (Pierannunzi et al., 2013).

Second, due to the limited information on PA, only the amount of exercise was asked and not the overall daily activities (such as sedentary), which may have an impact on the occurrence of MetS.

Third, the CHCIS is conducted annually, and members of the public participate voluntarily. The definition of change in exercise behavior in this study was based on the exercise behavior at the first screening compared to exercise behavior at the screening where MetS occurred. We ignored any changes in exercise behavior during the observation period as well as the exact time of its onset. This means that changes in PA could have happened after MetS was observed. However, the description of the change in exercise behavior in Table 3 showed that the consistency between the occurrence of MetS and the exercise behavior of the previous screening was quite high (89–97%), and it can be inferred that even though changes in PA may have happened after MetS appeared, this does not have a serious impact on the study results or its implications.

6. Conclusion

Using a large and long-term community cohort, we found sex differences in the effect of change in exercise behavior on the incidence of MetS, with positive changes in exercise behavior only reducing the occurrence of MetS for men.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that has been used is confidential.

Table A1

Hazard ratios (95% CI) for the incidence of MetS.

Variables	Men			Women		
	HR	95% CI		HR	95% CI	
Change in exercise behavior						
Maintain regular exercise	Ref.			Ref.		
Maintain irregular exercise	0.93	0.78	1.11	0.95	0.84	1.09
Maintain no exercise	0.79	0.68	0.92	1.00	0.90	1.11
Increase	0.85	0.73	0.98	0.94	0.85	1.04
Decrease	0.91	0.77	1.06	1.01	0.91	1.13
Number of screenings attended	0.52	0.48	0.564	0.49	0.46	0.52
Sociodemographic variable						
Age						
<65	Ref.			Ref.		
≥65	2.12	1.85	2.43	2.01	1.80	2.25
Education level						
Junior high school or below	1.13	0.97	1.32	1.34	1.17	1.54
Senior high school	1.16	0.99	1.35	1.13	0.97	1.31
College or above	Ref.			Ref.		
Degree of PA at work						
Light						
Moderate	0.91	0.80	1.02	0.96	0.87	1.07
Vigorous	1.00	0.87	1.14	0.83	0.74	0.93
Living area***						
City	1.09	0.94	1.26	0.99	0.90	1.09
Township	0.92	0.81	1.04	0.94	0.87	1.02
Village	Ref.			Ref.		
Personal health						
BMI***						
BMI < 24	Ref.			Ref.		
24 ≤ BMI < 27	1.84	1.63	2.07	1.68	1.55	1.82
BMI ≥ 27	2.17	1.88	2.50	1.80	1.64	1.97
Number of MetS components						
0	Ref.			Ref.		
1	2.25	1.84	2.74	2.46	2.18	2.78
2	4.41	3.64	5.35	4.48	3.97	5.06
Personal disease history						
Diabetes mellitus	1.45	1.20	1.76	1.47	1.26	1.72
Hypertension	1.40	1.22	1.59	1.47	1.33	1.62
Cardiac disease	0.95	0.74	1.22	1.13	0.96	1.34
Hyperlipidemia	1.19	0.95	1.49	1.17	0.98	1.39
Health-related behaviors						
Smoking						
Never						
Former	1.00	0.87	1.15	0.63	0.33	1.22
Current	1.19	1.05	1.35	1.16	0.78	1.72
Chewing betel nuts						
Never						
Former	1.04	0.90	1.21	2.87	0.98	8.40
Current	1.15	0.96	1.36	0.55	0.14	2.22
Drinking alcohol						
Never						
Former	1.2	0.9	1.5	0.25	0.06	1.06
Occasional	0.9	0.8	1.1	0.87	0.66	1.16
Frequent	1.0	0.9	1.2	0.97	0.87	1.08
Dietary habits						
Vegetable ≥ 3 bowls/day	1.03	0.89	1.18	1.10	1.00	1.22
Fruit ≥ 7 times/week	1.12	1.01	1.25	1.02	0.95	1.09
Little beverage	0.99	0.89	1.10	0.97	0.89	1.05
Little snack	0.97	0.87	1.07	1.10	1.03	1.18

Adjusted for all covariates: age, education, degree of PA at work, living area, BMI, number of screenings attended, number of MetS components, personal disease history, health-related behaviors (smoking, chewing betel nuts, drinking alcohol), and dietary habits (vegetables, fruit, beverages, snacks).

Appendix A

Table A1.

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