Step rate-determined walking intensity and walking recommendation in Chinese adults

Journal:	*BMJ Open*
Manuscript ID:	bmjopen-2012-001801
Article Type:	Research
Date Submitted by the Author:	13-Jul-2012
Complete List of Authors:	Wang, Huan; China Institution of Sports Science, mass sport zhang, Yanfeng; China Institute of Sport Science, mass sports XU, Liangliang; Shanghai Institute of Sport Science, , Center of Physical Fitness and Health Jiang, Chongmin; China Institute of Sport Science, mass sports
Primary Subject Heading:	Sports and exercise medicine
Secondary Subject Heading:	Public health
Keywords:	SPORTS MEDICINE, PUBLIC HEALTH, STATISTICS & RESEARCH METHODS

Step rate-determined walking intensity and walking recommendation in Chinese adults

Wang Huan[1], Zhang Yan-feng[1], Xu Liang-liang[2] ,Jiang Chong-min[1]

1. China Institute of Sport Science, Department of Mass Sports, Beijing 100061, China;
2. Shanghai Institute of Sport Science, Center of Physical Fitness and Health, Shanghai 200030, China

Corresponding author
Wang Huan, China Institute of Sport Science, Department of Mass Sports, Beijing 100061, China.
Tel：(8610) 87182583
Fax: (8610) 67103872
Email:huanwang55@yahoo.com

Key Words
Walking, Step rate, Energy expenditure, Physical activity

Words count： 2776

ABSTRACT

Purpose There is lack of data on the physiological characteristics of over ground walking and walking recommendations for Chinese adult. The purpose of the study is to measure walking-related energy expenditure during field testing, to identify step-rate cut point associated with moderate and vigorous intensity, and to translate physical activity (PA) guidelines into walking goals for Chinese adults.

Design cross sectional analytic study

Setting two communities from Beijing and Shanghai in China

Participants A sample of 226 Chinese adults (117 men, 109 women) with a mean age of 21.7 (±0.2) years, volunteered to participate in the study. All Participants were recreationally active without orthopedic limitations, free of chronic diseases, not taking any medications that affect metabolism, and non-smokers.

Outcome measures All the participants completed four 6-minute incremental over ground walking at different speeds of 3.8km/h,4.8 km/h,5.6 km and 6.4 km/h, respectively. Indirect calorimeter was used to measure energy expenditure at each speed. Receiver operating characteristic (ROC) curves were used to determine the step-rate cut points associated with moderate and vigorous intensity activity.

Results At the same walking speed，step counts per minute were higher in women than in men. No significant differences were found in VO_2 per weight（$ml{\cdot}kg^{-1}{\cdot}min^{-1}$）between women and men. Step-rate cut point associated with walking at 3METs and 6METs were 105 $step{\cdot}min^{-1}$and 130 $step{\cdot}min^{-1}$when analyzing men and women together. There were slight differences on the cut points between women and men if data were analyzed separately.

Conclusions In order to meet PA guidelines, Chinese adult should walk 30 minutes with at

least 105 step·min^{-1}, or 3,150 steps or 2 kilometers with the same step-rate per day. Walking at a higher speed of 130 step·min^{-1} might provide additional health benefit.

INTRODUCTION

Engaging in adequate amounts of physical activity has positive effect on energy balance, weight control, cardio-respiratory fitness and other health benefits**[1-5]**. It has been recommended that all adults perform at least 30 min of moderate-intensity aerobic activity 5 day each week to achieve health benefits of exercise, and physical activity of greater intensity or of longer duration can promote additional benefits to health**[3]**. Among all the activities, walking is regarded by public as the most common exercise**[6]**. Obviously it is a meaningful research area to explore how much walking are enough to meet Physical Activity Guideline.

Some steps-based walking recommendation is developed by researchers**[7-10]**. The most widely recognized step recommendation is to accumulate 10,000 steps per day. However, the goal of 10,000 steps per day is based on very limited evidence, may be unrealistic for many people**[11]**. In addition, it has not incorporated the activity intensity. Intensity is an important index of physical activity recommendations due to health benefits are depending on the intensity of activity**[12]**.

Step rate (step·min^{-1}) is one of the important parameters of walking gait and can be used to identify intensity in free-living walking**[13]**. In addition, step rate, as a simple indicator of ambulatory behavior, can be captured easily. More specific, if walking duration and step numbers are known, intensity (step rate) can be calculated, therefore, certain specific cut points (step·min^{-1}) can be used to indicate intensity categories. Recently, studies have been conducted to identify step rates that correspond to intensity classifications**[14-15]**. These studies have found that walking at a pace of 100step·min^{-1} corresponds to moderate intensity and this finding may be used to

promote public health recommendation of accumulating 3000 steps in 30 minutes to meet physical activity guidelines. Although these studies provide insightful data, there are limitations in their research methods. First, step rate cut points were obtained under controlled laboratory conditions, such as treadmill walking, which may differ from realistic activities (such as ground walking). Second, the small sample sizes from these previous studies limit its generalizability to larger population.

Physiological responses of physical activity are dependent on the biological characteristics of the study population, such as race, height, weight, gender, and age**[16]**. Most of current walking recommendation studies were based on Westerners**[17,18]**. No studies have been conducted in Chinese sample. It is well-known that China is experiencing rapid economic growth. In China, family owned vehicle is getting more popular; therefore, more people are driving instead of walking for daily activities. An evidence-based walking recommendation is in critical need for Chinese adults.

The purposes of this study were⑴to identify step rate threshold associated with moderate and vigorous intensity activity for Chinese adult, and⑵to translate PA guidelines into walking recommendation for Chinese adults.

METHODS

Participants

A community-based sample of 226 Chinese adults (117 men, 109 women) with a mean age of 21.7 (±0.2) years, volunteered to participate in the study. All Participants were recreationally active without orthopedic limitations, free of chronic diseases, not taking any medications that affect metabolism, and non-smokers. This study was reviewed and approved by China Institute of Sport Science Institutional Review Board. Participants provided written informed consent to participate in the study.

Walking Testing

For walking test, we applied the previously established method to control over ground walking speed[19]. Briefly, an indoor room at room temperature (22.5±0.7□), well ventilated, and with concrete floor was used. An area of 15m×10m rectangular field (circumference of 50m) was marked. Markers were placed on the edges (4 sides) of the field with 5m apart and used as tracking indicators while the subjects were walking along the edges. Participants were required to perform 4 walking tests at four different walking speeds 3.8km/h, 4.8km/h, 5.6km, and 6.4km/h for 6 minutes, respectively. During the test, participants were reminded of remaining natural gait, looking straight, and moving from one marker to the next. They took 10 minutes rest before the test, and 5 minutes rest between each test. It was proved that subjects could easily maintain the pre-set walking speed by following the instructions and markers on the ground, and also keep the normal, relaxed walking manner[19].

Energy expenditure was measured by the Cortex MetaMax 3B metabolic analyzer

(German). Steady-state VO_2 was recorded as an average of the last 2 minutes of each exercise bout. METs were calculated by dividing steady-state VO_2 by $3.5 ml \cdot ml^{-1} \cdot kg^{-1}$. Moderate intensity was defined as 3.00–5.99METs, while vigorous intensity for 6.00–8.99METs.

After participants reached the steady state at each walking speed level (after 3 minutes), the steps per min were recorded by a trained staff through hand counter. Numbers of steps were recorded twice at each walking speed, and the average value was calculated.

Height and Weight Measurement

Height was measured without shoes to the nearest 0.1centimeter using a calibrated electronic height meter. Weight was measured in light clothing and without shoes to the nearest 0.1 kg using a calibrated electronic scale. BMI was calculated as weight in kilograms (kg) divided by height in meters squared.

Statistics analysis

Descriptive statistics were expressed as mean ± SD for the physiological variables under each walking speed. Gender differences were tested using independent t-tests.

Step-rate cut points were determined using receiver operating characteristic (ROC) curves. ROC curves were developed to examine optimal cut points in terms of sensitivity (correctly identifying participants who were at moderate intensity or vigorous intensity activity) and specificity (correctly identifying those who were not at moderate intensity or vigorous intensity activity).

A level of 0.05 was used to determine significance for all statistics analysis. All analyses were performed using SPSS16.0.

Results

The characteristics of the study participants are presented in Table 1. Comparison between men and women regarding measured variables at each walking speed in men and women is presented in Table 2. The heart rate and VO_2 ($L \cdot min^{-1}$) in men were significantly higher (P＜0.05) than those in women at the same speed of walking. When VO_2 was adjusted for body mass, the sex effect disappeared. No significant differences were found in VO_2 per kg between women and men across different speeds.

Table 1. The characteristics of the study sample sexing men and women

Variable (Mean±SD)	Women	Men	All
n	109	117	226
Age(yr)	21.8±2.0	21.7±2.0	21.7±2.0
Height(cm)	166.2±5.4	175.7±5.0	170.1±6.1
Weight(kg)	59.6±8.3	69.1±8.4	64.5±9.6
BMI (kg/m^2)	21.5±2.5	22.4±2.4	22.0±2.5

BMI, body mass index; SD, standard deviation.

Table 2 also shows that under the same walking speed, the step rate was different among participants. At the same walking speed, step rate was higher in women than in men. Although higher step rate consumes more EE, there is no significant relationship between VO_2 and step rate at the same walking speed (Pearson Correlation coefficient r=0.28). The step rate increased accordingly while the walking speed increased in both men and women. There was significant correlation between step rate and VO_2 （Pearson Correlation coefficient r=0.73）.

Table 2 Comparison between men and women regarding measured variables at each walking speed

		Men		Women		P Value
		Mean	SD	Mean	SD	
3.8km/h	HR	83.2	10.3	87.8	9.1	0.02
	$VO_2(ml\cdot kg^{-1}\cdot min^{-1})$	10.47	0.67	10.32	0.69	0.25
	$VO_2(L\cdot min^{-1})$	0.72	0.05	0.61	0.04	＜0.00
	METs	2.93	0.21	2.91	0.19	0.78
	Step rate($step\cdot min^{-1}$)	95.71	3.12	97.46	3.36	＜0.00
4.8km/h	HR	93.3	11.1	102.3	9.6	＜0.00
	$VO_2(ml\cdot kg^{-1}\cdot min^{-1})$	13.94	1.41	13.58	1.63	0.82
	$VO_2(L\cdot min^{-1})$	0.97	0.12	0.82	0.14	＜0.00
	METs	4.02	0.45	3.96	0.61	0.40
	Step rate($step\cdot min^{-1}$)	113.06	6.25	115.68	5.85	0.001
5.6km/h	HR	102.2	11.6	113.4	11.0	＜0.00
	$VO_2(ml\cdot kg^{-1}\cdot min^{-1})$	15.99	1.72	15.94	1.86	0.84
	$VO_2(L\cdot min^{-1})$	1.10	0.14	0.95	0.18	＜0.00
	METs	4.58	0.50	4.58	0.71	0.95
	Step rate($step\cdot min^{-1}$)	119.61	6.22	123.01	6.93	＜0.00
6.4km/h	HR	114.2	14.3	126.9	12.9	＜0.00
	$VO_2(ml\cdot kg^{-1}\cdot min^{-1})$	19.07	2.29	19.02	2.66	0.88
	$VO_2(L\cdot min^{-1})$	1.32	0.19	1.14	0.21	＜0.00
	METs	5.46	0.67	5.50	0.93	0. 74
	Step rate($step\cdot min^{-1}$)	126.01	7.02	131.00	8.40	＜0.00

HR, heart rate; METs, metabolic equivalent, divide VO_2 by $3.5ml\cdot ml^{-1}\cdot kg^{-1}$;

There were significant differences between MET value calculated from measured VO_2 with recommended value from PA Compendium**[20].** The measured METs was significantly higher than recommended value at 4.8km/h, 5.6km/h and 6.4km/h, respectively (Figure 1).

The different cut point regarding step rate among men and women is shown in Table 3. According to MPA and VPA identified from indirect calerometry, ROC-curve suggested that the optimal step-rate cut point was 105 step·min^{-1} for MPA with 85% sensitivity and 74% specificity. For the VPA cut-point, the optimal step-rate was 130 step·min^{-1} with 96% sensitivity and 67% specificity. Women had slightly higher cut point than men.

Table 3 Step rate(step·min^{-1}) cut-points associated with MPA and VPA in women and men from the present study and other literatures

Intensity classification		The present study (ROC analysis)	Simon J et al [14]		Tudor et al [15]	Beets MW et al [26]	Rowe DA et al [27]
			Linear regression analysis	ROC analysis			
MPA (3METs）	All	105	89	107	100	100 (85-111)*	100 (90-113)*
	Men	104	92	102	96		
	Women	107	91	115	107		
VPA (6METs)	All	130	ND	ND	130	ND	ND
	Men	127			125		
	Women	137			136		

ROC, receiver operating characteristic curves used to determine the step-rate cut points

ND, no data provided

*The range of step rate based on difference of leg length[26] and height[27]

Discussion:

The main purpose of this study was to use indirect calorimeter to identify a step-rate cut-point associated with activity intensity in a field environment. To our knowledge, this was the first attempt to establish a walking target for Chinese people. We identified the optimal step-rate cut point was 105step·min^{-1} for MPA and 130step·min^{-1} for VPA. Applying cut-point for MPA to calculate the walking steps and distance taken to meet PA guidelines, 30minutes of moderate-intensity activity corresponds to 3,100 steps in men and 3,200 steps in women, or roughly 3150 steps for both. If steps are converted to walking distance, it is about 2 km.

We tested 4 different walking speeds in this study. Three of them were significantly corresponded with PA Compendium**[20]**.When compared with EE reference from PA Compendium, the EE measured from our study was higher for three walking speeds. Previous studies showed inconsistent results when comparing measured EE with compendium reference. Some reported higher value**[21]**, others reported lower value**[22-23]**. The inconsistency might be due to difference in sample characteristics, testing methods, and test environment **[21,24,25]**. Therefore, it is not proper to perform complete result comparisons for different test condition. For the current study test setting might be a contributor to the difference. We conducted the walking test in a field setting, not on a treadmill. Our previous study found that walking-related energy expenditure in the field was different from treadmill testing**[19]**. However, the intensity of these 3 walking speeds in present study was between 4.0 and 5.5 MET, which was in the range of 3-6 MET as moderate intensity identified by PA Compendium.

Objective measurement method and larger sample size allowed this study to establish the step rate cut point related to intensity (METs) as a minimum threshold for MPA walking and VPA walking. To date, four other studies have used indirect calorimeter to validate a step-rate cut point associated with moderate or vigorous intensity walking. Simon J measured the step rate and intensity on treadmill**[14]**. Different cut-points were obtained from different statistical method, and the author concluded walking at 100 step·min^{-1}on ground level would meet the moderate-intensity walking recommendation. Tudor-Locke and his colleagues determined that 96 and 107 step·min^{-1} as the minimum threshold for moderate-intensity walking, and 125 and 136 step·min^{-1}for vigorous-intensity for young men and women**[15]**. The two other studies supported the 100 step·min^{-1}as moderate-intensity walking cadence while emphasized inter-individual variation of step rate were apparent due to anthropometric differences such as height and leg length**[26,27]**. Our finding corresponded closely with these previous studies, although our cut-point was slightly higher. The similar findings of these studies are encouraging given the differences between the sample characteristics and methodologies, which offer some evidence that will support the development of a consensus step rate recommendation for the people in different countries.

In addition, we found that there was significant difference of step rate between men and women at the same walking speed, therefore it seems proper to have different cut point recommendation for men and women separately. The gender differences in the mean step rate may be caused by differences in height and leg-length. At the same walking speed, female's step frequency is higher than male due to shorter height and shorter lower limb. However, since the difference of step rate between men and women was less than 10 steps per min, considering the needs to establish the walking recommendation in a relatively simple way, we think that single step rate recommendation would be more effective in physical activity promotion and intervention application. Therefore, we suggest 105 step·min^{-1} and 130 step·min^{-1} cut-points to be corresponded to MPA and VPA. However, if the recommendations of individualized step rate would be developed in the future, physical differences such as height, leg length and gender should also be considered.

In order to associate our step rate cut point with PA guideline**[3]**, the minimum walking steps of 3,150 steps daily for MPA were considered based on our study results. It should be emphasized that 3,150 steps need to be taken above the basic number of daily steps**[15]**. Recent study has reported the daily walking steps goal for American people is 8000 steps, derived from accelerometer data**[10]**, but earlier study reported 10000 steps**[8]**. Since people have different physical activity patterns, it is difficult to establish consistent total number of walking steps for everyone. Moreover, there is not a comprehensive walking recommendation if only walking steps is involved but not the intensity. Therefore, it is practical and useful to provide a general suggestion that how many extra steps individual needs to take above the daily activities and how fast to walk for health promotion. Specially, Chinese adult should walk at least 30 minutes with a minimal 105 steps/min, or 3150 steps or 2 kilometers with the same step rate daily to meet PA guidelines. They will perform vigorous-intensity activity if 130 step·min^{-1} is reached and this will provide more health benefit.

China is experiencing rapid economic growth. With the increase of private car ownership and the reduction of the intensity of work, a rapid decrease of physical activity levels of Chinese people has caused widespread concern. Data from 2002 China Nutrition and Health Survey showed that only 33% urban population used walking as their main transportation, with an average 26 minutes per day of walking**[30]**. Although the latest data from 2012 survey are not available, it is most likely that the level of walking continues to decline. Therefore, a walking recommendation built on scientific evidence for Chinese adults is a meaningful step to help people lead an active life.

One strength of the present study was large sample size and EE measurement in field settings, which provide sufficient power to identify the step rate cut- points accurately. Another strength was to provide Chinese adults a walking recommendation in form of relative flexible assistive tool. People can achieve their own exercise goal by using different calculations, such as step rate, walking during, total walking steps, and/or walking distance. There were a number of limitations in this study. The first limitation was the small age range of young participants. It was known that gait and energy expenditure will be different between older and young individuals**[28]**. At the same walking speed, older people will have the gait of shorter step length and faster step rate**[29]**.Therefore, the cut point established might not be suitable for older population. The second limitation was the use of a constant (3.5 $ml \cdot kg^{-1} \cdot min^{-1}$) as an estimated value of resting energy expenditure, instead of a direct measurement for calculating METs. Although the use of this constant is widely accepted in the scientific literature, it is likely to overestimate resting-energy expenditure at the individual level**[23-24]**. Then, the step rate cut point developed by the estimated value of MET might be overestimated. The third of limitation was lack of cross-validation. Future study should focus on establishing the validity of the current cut points through independent validation studies in real-life field walking.

Conclusion:

The step rate cut-points corresponding to activity intensity categories (in terms of MET levels) have been set up by this study. It could be useful for recommending appropriate amounts of walking exercise to meet PA guidelines for Chinese young adults. The findings from this study indicate that Chinese young adult should walk at least 30 minutes with a minimal 105 step·min^{-1}, or 3150 steps with the same step rate daily to meet PA guidelines. There were slight differences on step-rate threshold and minimal steps between women and men, so further specific step rate recommendations can be developed for different gender group.

What this study adds

1. This study shows that under the same walking speed, the step rate difference between individuals led to small changes of energy expenditure. When the walking speed increased from 3.8km/h to 6.4 km/h, step rate and energy expenditure increased almost at the same rate.
2. This study also shows at the same walking speed, step rate was higher in women than in men, but the difference is less than 10 step•min^{-1}.
3. This study compares the data from Chinese people's walking energy expenditure with other findings based on western participants and set up the walking recommendation for Chinese people for the first time.

Contributors All authors were involved with the planning and designing of the study, as well as data collection. Wang Huan was responsible for the first draft of the manuscript, which was subsequently revised by all other authors.

Acknowledgements The author thank the contribution of Dr Steven Blair and Dr Xue-mei Sui, who provided additional information for data analysis and careful modification for their the text of this paper.

Competing interests None.

Project and Funding

National Key Technology Support Program（2006BAK33B03）was funded by Ministry of Science and Technology (MST) in China

REFERENCES

1. Caspersen CJ, Fulton JE. Epidemiology of walking and type 2 diabetes. *Med Sci Sports Exerc* 2008;**40**(7suppl):S519–28.

2. Eyler AA, Brownson RC, Bacak SJ, et al. The epidemiology of walking for physical activity in the United States. *Med Sci Sports Exerc* 2003;**35**:1529–36.

3. Haskell WL, Lee IM, Pate RR, et al. Physical activity and public health: updated recommendation for adults from the American College of Sports Medicine and the American Heart Association. *Med Sci Sports Exerc* 2007;**39**:1423–1434.

4. Hamer M, Chida Y. Walking and primary prevention: a meta-analysis of prospective cohort studies. *Br J Sports Med* 2008;**42**:238–43.

5. Lee IM, Buchner DM. The importance of walking to public health. *Med Sci Sports Exerc 2008*;**40**(7 suppl):S512–8.

6. Workman JM, Armstrong BW. Metabolic cost of walking: equation and model. *J Appl Physiol* 1986;61(4):1369-1374.

7. Tudor-Locke C, Ainsworth BE, Thompson RW, et al. Comparison of pedometer and accelerometer measures of free-living physical activity. *Med Sci Sports Exerc* 2002;**34**: 2045–2051.

8. Tudor-Locke C, Bassett DR. How many steps/day are enough? Preliminary pedometer indices for public health *Sports Med* 2004;34: 1–8.

9. Tudor-Locke C, Hatano Y, Pangrazi RP, et al, Revisiting “how many steps are enough?” *Med Sci Sports Exerc* 2008;40:S537–S543.

10. Tudor-Locke C, Johnson WD, Katzmarzyk PT. Accelerometer-determined steps per day in US adults. *Med Sci Sports Exerc* 2009;**41**: 1384–1391.

11. Wilde BE, Sidman CL, Corbin CB. A 10,000-step count as a physical activity target for sedentary women *Research Quarterly for Exercise and Sport* 2001;(72)4:411-414.

12. Pearce ME, Cunningham DA, Donner AP, et al. Energy cost of treadmill and floor walking at self-selected paces. *Eur J Appl Physiol Occup Physiol*. 1983;52(1):115-9.

13. Tudor-Locke C, Rowe DA. Using Cadence to Study Free-Living Ambulatory Behaviour. *Sports Medicine* 2012;**3**: 1-17.

14. Simon J Marshall, Susan SL, Karen MW, et al. Translating Physical Activity Recommendations into a Pedometer-Based Step Goal. *Am J Prev Med* 2009;**36**:410–415.

15. Tudor-Locke C, Sisson SB, Collova T, et al. Pedometer-determined step count guidelines for classifying walking intensity in a young ostensibly healthy population. *Can J Appl Physiol* 2005;**30**: 666-676.

16. Morris JN, Hardman AE. Walking to health. *Sports Med* 1997;**23**:306–32.

17. Bertram JE, Ruina A. Multiple Walking Speed-frequency Relations are Predicted by Constrained Optimization. *J Theor Biol* 2001;209:445-453.

18. Zarrugh MY, Radcliffe CW. Predicting Metabolic Cost of Level Walking. *Europ J Appl Physiol* 1978;38: 215-223.

19. Jiang Chongmin, Qiu Shumin, Wang Huan. Comparison of treadmill and field

test for energy consumption during running and walking. *Sport Science(China)* 2010;7:30-37.

20. Ainsworth BE, Haskell WL, Whitt MC, et al. Compendium of physical activities: an update of activity codes and MET intensities. *Med Sci Sports Exerc* 2000;**32**(Suppl. 9):S498–51.
21. Anjos LA, Wahrlich V, Bossan FM, et al. Energy expenditure of walking at different intensities in Brazilian college women. *Clinical Nutrition* 2008; 27:121–125.
22. Byrne NM, Hills AP, Hunter GR, et al. Metabolic equivalent: one size does not fit all. *J Appl Physiol* 2005;**99**:1112–9.
23. Gunn SM, Brooks AG, Withers RT, et al. Determining energy expenditure during some household and garden tasks. *Med Sci Sports Exerc* 2002;**34**:895–902.
24. Gunn SM, van der Ploeg GE, Withers RT, et al. Measurement and prediction of household energy expenditure in males during household and garden tasks. *Eur J Appl Physiol* 2004;**91**:61–70.
25. HALL C, A FIGUEROA, B FERNHALL, et al. Energy Expenditure of Walking and Running: Comparison with Prediction Equations. *Med Sci Sports Exerc* 2004;**36**: 2128–2134.
26. Beets MW, Agiovlasitis S, Fahs CA, et al. Adjusting step count recommendations for anthropometric variations in leg length. *J Sci Med Sport* 2010; **13**:509-12.
27. Rowe DA, Welk GJ, Heil DP, et al. Stride rate recommendations for moderate intensity walking. *Med Sci Sports Exerc* 2011; **43**:312-318.

28. Demura S, Sohee S, Yamaji S. Sex and age differences of relationships among stepping parameters for evaluating dynamic balance in the elderly. *J Physiol Anthropol.2008*; **27**:207-15.

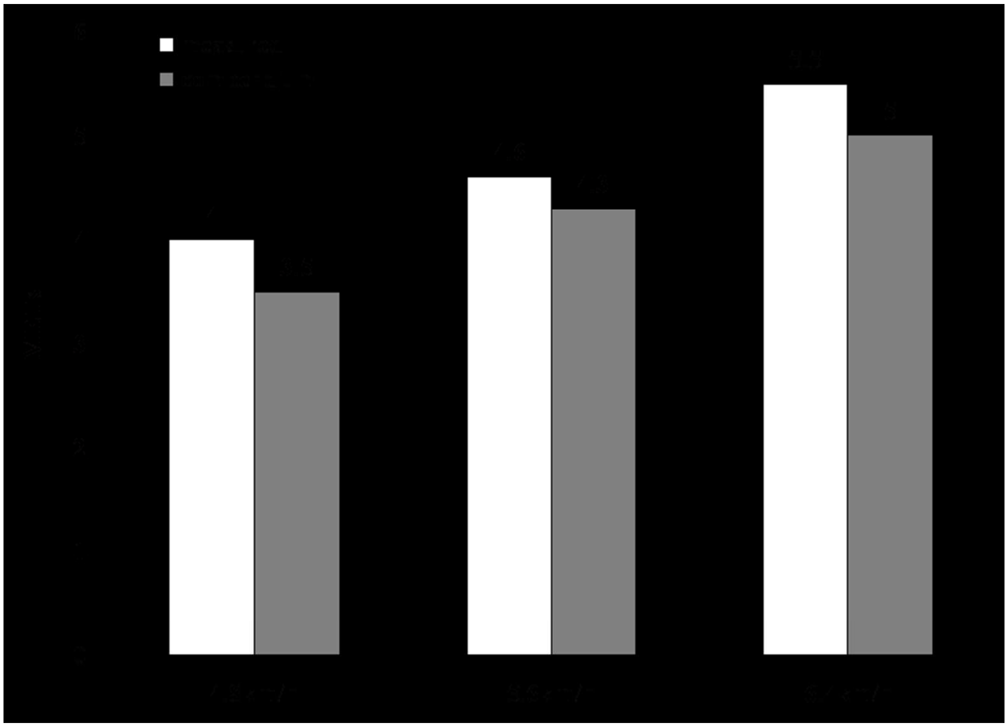
29. Cavagna GA, Franzetti P. The Determinants of the Step Frequency in Walking in Humans. *J Physiol* 1986; 373:235-242.

30. Liu Ailing, Hu Xiaoqi, Li Yanping. Modes of Transportation by Chinese Non-agriculture Employed Population. *Chin J Prev Contr Chron Dis* 2009;2:114-116.

FIGURE LEGEND

White column: Measured value

Black column: PA Compendium recommendation



caption:Comparison of MET value from the present study with PA Compendium
legend: white column measured value
black column PA compendium
222x160mm (96 x 96 DPI)

文章编号:1000-677X(2011)07-0030-07

体育科学
2011 年(第 31 卷)第 7 期
CHINA SPORT SCIENCE
Vol. 31, No. 7, 30-36, 2011.

平板运动跑台和场地环境测试走、跑运动能量消耗的比较研究

Comparison of Treadmill and Field Test for Energy Consumption during Running and Walking

江崇民[1], 邱淑敏[2], 王 欢[1], 牟希涛[3], 张彦峰[1], 尚文元[1]
JIANG Chong-min[1], QIU Shu-min[2], WANG Huan[1], MOU Xi-tao[3], ZHANG Yan-feng[1], SHANG Wen-yuan[1]

摘 要: 目的: 通过平板运动跑台和场地两种不同的测试方法, 对我国成年男性走、跑过程中的气体代谢和能量消耗进行比较。方法: 15 名成年男性在平板运动跑台和场地完成 4.8 km/h、6.4 km/h、8.0 km/h 三个速度的走、跑运动, 使用 Cortex MetaMax 3B 测定走、跑过程中的气体代谢指标变化并进行统计分析。结果: 走、跑时平板运动跑台测试和场地测试之间气体指标、心率和能量消耗指标有明显差异。两种测试方法得来的数据存在线性相关。使用 ICC 系数和 Bland-Altman 法分析表明两种测试方法有非常显著的一致性和相关性。结论: 相同速度下平板运动跑台走、跑和场地走、跑的能量消耗差异显著, 只有直接测量场地走、跑的能量消耗才能反映日常生活中和体育健身活动中走、跑运动的真实状况。应用直线回归分析建立了平板运动跑台测试和场地测试两种方法之间的转换推导公式, 根据跑台测试结果推算场地测试耗氧量和能量消耗, 但由于样本量较少, 该公式还需要进一步增加样本量进行验证。

关键词: 平板运动跑台测试; 场地测试; 能量消耗

Abstract: Objective: The purpose of this study was to compare treadmill and field test for energy cost during running and walking in adult males, to analysis the differences and establish the conversion formula. Methods: 15 adult males on the treadmill and on the field complete 4.8 km/h, 6.4 km/h, and 8.0 km/h walking and running. The gas metabolism was determined using the Cortex MetaMax 3B. Results: 1) The indicator of gas index, heart rate and energy cost were very different during running and walking. 2) There is a linear correlation between two sets of data. 3) ICC and Bland-Altman method between the two groups proved that there was a significant consistency and relevance in the data of two sets. Conclusion: 1) There is significant difference between the energy cost of treadmill and field test. Only the direct field measurement reflects the true state of running and walking of daily life and physical activity. 2) Established a conversion formula of oxygen consumption and energy consumption between treadmill test and field test by linear regression method, but the formula need to further for validation because of the small sample size.

Key words: *treadmill test; field test; energy consumption*
中图分类号: G804.49 文献标识码: A

1 前言

走、跑是人体运动的基本方式, 同时也是促进健康的常用方法, 准确测量其能量消耗对于运动处方非常重要[1-7]。通过间接测热法测量不同速度走、跑运动时的摄氧量可以为预测每天的能量消耗提供依据[22,23]。以往由于测量仪器不便于携带, 测量走、跑运动时的摄氧量被限制在平板运动跑台上完成[30]。随着便携式气体代谢仪的不断更新[12], 走、跑的能量消耗可以在场地环境中测试。平板运动跑台和场地走、跑虽然运动形式差别不大, 但不同的气体环境、不同的地面以及不同的运动模式可能会对其

收稿日期: 2011-05-11; 修订日期: 2011-06-20
基金项目: 国家科技支撑计划课题(2006BAK33B03)。
作者简介: 江崇民(1962-), 男, 山东青岛人, 研究员, 博士, 主要研究方向为体质测量与评价、大众健身理论与方法, Tel: (010)87182582, E-mail: jiangchongmin@263.net。
作者单位: 1. 国家体育总局体育科学研究所, 北京 100061; 2. 中央财经大学 体育经济与管理学院, 北京 100081; 3. 北京体育大学, 北京 100084
1. China Institute of Sport Science, Beijing 100061, China; 2. Central University of Finance and Economics, Beijing 100081, China; 3. Beijing Sport University, Beijing 100084, China.

气体代谢和能量消耗的指标测定结果造成影响。

对平板运动跑台测试和场地测试的不同的研究已经有过较多文献报道。Parvataneni 等在研究平板运动跑台和场地走、跑(速度约等于 3.8 km/h)的步态和摄氧量的对比中发现，步态分析中两组的时间参数、运动学参数、动力学参数类似，但在平板运动跑台走、跑的心率和摄氧量均大于场地的走、跑[21]。Meyer 等对比了 18 名男性在平板运动跑台和场地环境走、跑测试的摄氧量，受试者从 7.2 km/h 的速度开始递增强度，运动约 11 min，发现受试者平板运动跑台测试时摄氧量显著高于场地测试($P < 0.001$)，且场地测试时个体达到最大摄氧量的时间明显增长[16]。这些研究结果提示了两种测试方法的差别，由于受试者、测试方案以及测试方法的不同，很难对平板运动跑台测试与场地测试之间的区别形成定论。

在中国，研究者已经开始重视走、跑运动时的能量消耗问题，如采用各种仪器对走、跑各种速度的能量消耗测定[2]，对走、跑的自然速度、步幅、步频、能量消耗水平进行研究[1]等，但关于走、跑的运动负荷及变化和测量方法对能量消耗的影响的研究并不多。一般来说，场地测试结果的重复性不如实验室测试，但由于更加接近真实环境，数据更加真实。由于平板运动跑台测试无法体现场地走、跑的表现和用力程度，测试结果与场地走、跑的真实能量消耗可能存在偏差。基于此，本研究拟对我国成年男性在平板运动跑台和场地两种不同的测试环境完成走、跑运动时的气体代谢和能量消耗特点进行研究，对两种测试方法的差异进行探讨，分析差异存在的原因和两者之间的转换推导公式。

2 研究对象与方法

2.1 研究对象

随机选择 15 名成年男性，平均年龄为 23 岁，年龄最小者 20 岁，年龄最大者 26 岁，锻炼习惯为每周有大于 6 h 中等强度的运动(表 1)。受试者经病史和体格检查，均无呼吸系统、心血管系统、内分泌系统等方面的疾病。

表 1 研究对象一般情况一览表

性别	n	年龄(岁)	身高(cm)	体重(kg)	体重指数 BMI	体脂率(%)
男性	15	23±3	174.2±5.1	68.3±11	22.5±3.4	17±9.4

2.2 研究方法

2.2.1 测试方案和环境

实验在非连续的两天内完成。由于预实验中选择了其他 7 名受试者先后进行了平板运动跑台测试—场地测试—平板运动跑台测试，两次平板运动跑台测试中的摄氧量没有明显差别。因此，正式实验中受试者先进行平板运动跑台测试，后进行场地测试，没有进行交叉对比。

受试者的测试顺序相同，测试前 12 h 清淡饮食、无剧烈活动、未吸烟及饮用含有咖啡因的饮料。测试时受试者穿上舒适全棉的运动服和运动鞋，空腹 2~3 h 后进行。

2.2.1.1 平板运动跑台测试

测试前，受试者在平板运动跑台(VIASYS LE500CE)进行适应性运动(佩戴好面罩) 3 min。测试开始后嘱受试者手握扶手在平板运动跑台上站立 5 min，完成安静状态下数据的采集，然后每人完成 4.8 km/h(3mph)、6.4 km/h(4mph)、8.0 km/h(5 mph) 3 个速度的走、跑，坡度设置为 0，每个速度 6 min，运动过程中受试者不握扶手，连续运动共 18 min。平板运动跑台测试所在实验室温度为 21.7℃±1.5℃，测试环境 O_2 浓度为 23.93%，CO_2 浓度为 0.03%。

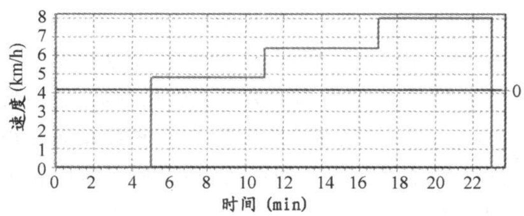


图 1 平板运动跑台测试负荷递增示意图

2.2.1.2 场地测试

场地测试在 20×15 m 的室内会议室进行，地面为木地板，环境温度为 22.5℃±0.7℃，测试环境 O_2 浓度为 23.93%，CO_2 浓度为 0.03%，通风状态良好。选用 15×10 m(周长为 50 m)的长方形场地一块，每 5 m(8.0 km/h 时每 10 m)间隔放置一个黄色标志物，测试时受试者需沿着场地标志物外侧缘行走和跑步。测试前先采集安静数据 5 min，然后完成 3 个速度的运动，从低到高依次为 4.8 km/h(走)、6.4 km/h(走)、8.0 km/h(跑)。每个速度 6 min，连续运动共 18 min。设置音频为 3.75 s、2.82 s、4.50 s 出现提示音一次，此时受试者需从第一个标志物移动至下一个标志物，受试者目视前方，以自然步态保持匀速行走或者跑步。走、跑过程中测试人员对受试者进行提醒，让其速度始终跟上音频的节奏，到 6 min 速度提升时，测试者对受试者做出口头提示，让受试者跟上音频的节奏开始慢跑。

2.2.2 测试设备

两种测试方法采用同一个便携式气体代谢仪 Cortex MetaMax 3B 对受试者走、跑进行气体代谢测定，根据受试者的脸型采用合适的面罩，同一受试者两次测试面罩相同。Cortex MetaMax 3B 的硬件版本为 2.7.0，硬件日期 2010 年 5 月 26 日，校准值为：O_2 系数 1.347011，CO_2 系数 0.989023，呼气量系数 1.012527，吸气量系数 1.080979，O_2 偏移量 -0.088117，CO_2 偏移量 -0.011868，气压传感器偏移量 145。该设备使用原理为每次呼吸测量法，对运动过程中每分通气量、O_2 浓度、CO_2 浓度及环

境温度、气压等参数实时进行数据采集。

测试过程中采用同一个心率表(Polar, Finland)。身高的测量采用鑫东华腾 GJ-II(自动)身高测试仪,体重采用高精度数显电子人体秤 RCS-160。身体脂肪含量采用 GE 双能 X 线吸收扫描仪 DXA(prodigy, GE Lunar Corp., Madison, 分析软件版本 4.0);X 线(38 kVp/76 kVp)束形扫描;BMD 精度:< 1.0%。

2.3 数据处理

采用 Cortex MetaMax 3B 气体代谢仪配备软件 MetaSoft 3.9 对收集数据进行处理,选取摄氧量($\dot{V}O_2$)、相对摄氧量($\dot{V}O_2$)、CO_2 呼出量($\dot{V}CO_2$)、呼吸交换率(RER)、每分通气量(VE)、能量消耗(EE)、相对能量消耗(EE)等指标,显示该指标在测试 10 s 时间间隔的均数,读取受试者走、跑每个速度时稳定状态下的平均值。

采用 SPSS 10.0 for Windows 统计软件包对测试结果进行统计分析,经正态分布及方差齐性检验后,采用均数和标准差($\overline{X}\pm SD$)描述连续性变量,对两种测试方法得来的数据进行配对 t 检验、直线相关分析、ICC(组内相关系数, Intraclass Correlation Coefficient)和 Bland-Altman 一致性分析,$P< 0.05$ 为具有显著的统计学意义,$P< 0.01$ 为具有非常显著的统计学意义。

3 结果与分析

3.1 平板运动跑台测试和场地测试的气体代谢指标变化

从表 2 中可以看到,安静状态下平板运动跑台测试和场地测试之间气体代谢指标差别不大;走、跑速度为 4.8 km/h 和 6.4 km/h 时,场地测试的各项测试结果均低于平板运动跑台测试测试结果,且有非常显著的统计学意义($P< 0.01$)。走、跑 8.0 km/h 时,场地测试的各项指标均大于平板运动跑台测试,场地测试的摄氧量/体重和摄氧量/去脂体重明显高于平板运动跑台测试,有非常显著的差异($P< 0.01$),CO_2 呼出量和每分通气量也明显高于平板运动跑台测试($P< 0.05$)。

3.2 平板运动跑台测试和场地测试的心率和能量消耗变化

从表 3 中可以看到,安静状态下,场地测试时的能量消耗/体重低于平板运动跑台测试,有显著的统计学差异($P< 0.05$);走、跑速度为 4.8 km/h 和 6.4 km/h 时,场地测试的心率和能量消耗值均低于平板运动跑台测试测试结果,且能量消耗值的变化有非常显著的统计学意义($P< 0.01$)。走、跑 8.0 km/h 时,场地测试的各项指标均大于平板运动跑台测试,但只有心率和能量消耗/体重的变化具有显著性差异($P< 0.05$)。

表 2 本研究平板运动跑台测试和场地测试不同速度走、跑时的气体代谢指标比较一览表

	测试方法	n	摄氧量 (l/min)	摄氧量/体重 (ml/min/kg)	摄氧量/去脂体重 (ml/min/kg)	二氧化碳产量 (l/min)	呼吸商	每分通气量 (l/min)
安静	平板运动跑台测试	15	0.454±0.076	5.58±0.65	8.12±1.00	0.375±0.054	0.83±0.07	10.9±1.4
	场地测试	15	0.439±0.077	5.37±0.68	7.82±0.89	0.379±0.092	0.86±0.08	10.9±2.4
	P		0.328	0.331	0.321	0.870	0.475	0.986
	增加% #		-3	-4	-4	1	4	0
4.8 km/h	平板运动跑台测试	15	1.398±0.177	17.27±2.05	25.08±2.62	1.125±0.144	0.81±0.05	26.4±3.6
	场地测试	15	1.210±0.191**	14.83±1.57**	21.64±2.36**	0.973±0.165**	0.81±0.03	23.8±4**
	P		0.000	0.000	0.000	0.000	0.816	0.002
	增加% #		-13.4	-14	-14	-14	0	-10
6.4 km/h	平板运动跑台测试	15	1.908±0.271	23.51±2.49	34.18±3.66	1.686±0.263	0.88±0.05	37.2±6.1
	场地测试	15	1.701±0.337**	21.24±2.14**	30.38±4.55**	1.535±0.289**	0.88±0.04	34.7±6.3*
	P		0.002	0.003	0.002	0.003	0.867	0.012
	增加% #		-11	-10	-11	-9	0	-7
8.0 km/h	平板运动跑台测试	15	2.722±0.408	33.50±3.55	48.80±5.74	2.483±0.373	0.91±0.05	54.0±9
	场地测试	15	2.914±0.473	35.62±3.02**	52.20±6.75**	2.719±0.537*	0.93±0.06	60.2±14.6*
	P		0.344	0.001	0.002	0.011	0.253	0.015
	增加% #		7	6	7	10	2	11

注:* 与平板运动跑台测试有显著的统计学差异($P< 0.05$);** 与平板运动跑台测试有非常显著的统计学差异($P< 0.01$);# 增加% = (场地测试均值 - 平板运动跑台测试均值)/平板运动跑台测试均值 × 100%;表 3、表 4 同。

表 3 本研究平板运动跑台测试和场地测试不同速度走、跑时的心率和能量消耗变化一览表

状态	分组	n	心率(beats/min)	能量消耗值(kcal/min/kg)	能量消耗/体重(kcal/min/kg)
安静	平板运动跑台测试	15	88±12	1.83±0.29	0.03±0.00
	场地测试	15	82±7	1.77±0.32	0.02±0.01*
	P		0.075	0.362	0.041
4.8 km/h	平板运动跑台测试	15	113±16	5.59±0.69	0.08±0.01
	场地测试	15	103±7*	4.82±0.77**	0.07±0.01**
	P		0.019	0.000	0.000
6.4 km/h	平板运动跑台测试	15	136±18	7.78±1.11	0.12±0.01
	场地测试	15	125±10*	7.06±1.30**	0.10±0.01**
	P		0.029	0.002	0.003
8.0 km/h	平板运动跑台测试	15	163±15	11.17±1.65	0.17±0.02
	场地测试	15	166±14*	11.96±1.99	0.18±0.02**
	P		0.044	0.063	0.001

3.3 平板运动跑台测试和场地测试摄氧量和能量消耗的净改变

为了排除安静状态下的测试数据对于走、跑测试数据的干扰，对摄氧量和能量消耗的净改变进行数据分析和统计（表 4），净改变＝走、跑时测试数值－安静时测试数值。

表 4 本研究平板运动跑台测试和场地测试在不同速度走、跑时的摄氧量和能量消耗净改变一览表

	分组	摄氧量(l/min)	摄氧量/体重(ml/min/kg)	能量消耗(kcal/min/kg)	能量消耗/体重(kcal/min/kg)
4.8 km/h	平板运动跑台测试	0.944±0.13	14.02±2.07	3.76±0.51	0.06±0.01
	场地测试	0.772±0.13**	11.37±1.36**	3.05±0.51**	0.05±0.01**
	P	0.000	0.000	0.000	0.000
	增加% #	－18	－19	－19	－17
6.4 km/h	平板运动跑台测试	1.584±0.36	23.22±3.78	5.95±0.89	0.09±0.01
	场地测试	1.263±0.29**	18.50±2.79**	5.30±1.07**	0.08±0.01*
	P	0.000	0.000	0.003	0.014
	增加% #	－20	－20	－11	－11
8.0 km/h	平板运动跑台测试	2.268±0.36	33.48±4.08	9.35±1.45	0.14±0.02
	场地测试	2.475±0.42**	36.40±3.34**	10.19±1.76**	0.15±0.01**
	P	0.001	0.001	0.002	0.001
	增加% #	9	9	9	7

从表 4 中可以看到，两种测试方法在 3 个速度下走、跑的摄氧量和能量消耗净改变均有显著差异。走、跑速度为 4.8 km/h 和 6.4 km/h 时，平板运动跑台测试的摄氧量和能量消耗净改变高于场地测试；走、跑 8.0 km/h 时，场地测试的各项指标均大于平板运动跑台测试，均有非常显著的差异（$P < 0.01$）。

3.4 平板运动跑台测试与场地测试测量指标的直线相关性

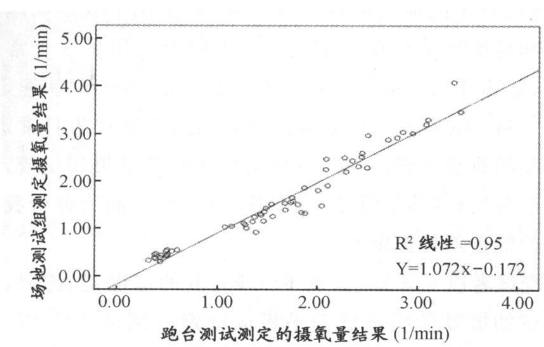


图 2 平板运动跑台测试和场地测试摄氧量比较散点图

将平板运动跑台测试与场地测试的主要测试指标（摄氧量、CO_2 呼出量、通气量、能量消耗值）进行直线相关和回归分析（图 2～图 5），两组的 4 个指标之间均存在线性相关，且 4 个指标的回归方程中斜率和截距均具有统计学意义（$P < 0.01$）。4 个指标中，摄氧量和能量消耗值的相关系数较高（$R^2 \geqslant 0.95$），表明该直线回归方程的斜率和截距可靠，可用来预测平板运动跑台测试和场地测试之间的系统误差。直线回归方程为：场地测试摄氧量（l/min）＝1.072×跑台测试摄氧量（l/min）－0.172；场地测试能量消耗（kcal/min）＝1.078×跑台测试能量消耗（kcal/min）－0.700。

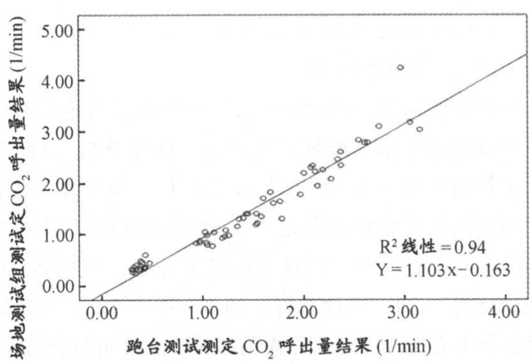


图 3 平板运动跑台测试和场地测试 CO_2 呼出量比较散点图

3.5 平板运动跑台测试和场地测试测量指标的 ICC 系数

ICC 系数（组内相关系数）反映两组数据之间的一致性，为个体的变异度除以总的变异度，其值介于 0～1 之间，0 表示不可信，1 表示完全可信，ICC 系数低于 0.40 表示一致性较差，大于 0.75 表示一致性良好[5]。从表 5 可以看出，平板运动跑台测试和场地测试的主要测试指标之间 ICC 系数均大于 0.75，显示出非常显著的一致性（$P < 0.01$）。

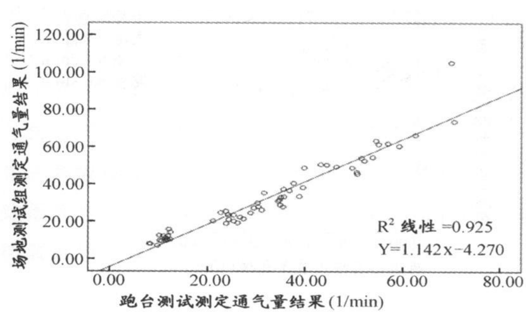


图 4 平板运动跑台测试和场地测试通气量比较散点图

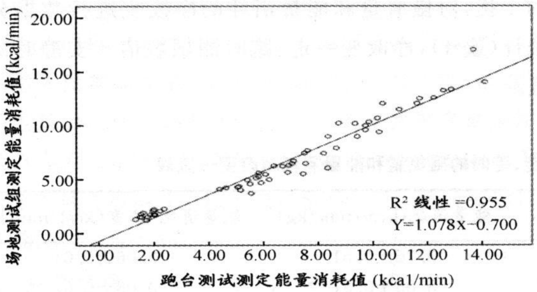


图 5　平板运动跑台测试和场地测试能量消耗值比较散点图

表 5　本研究平板运动跑台测试和场地测试测量指标的 ICC 系数一览表

	ICC 系数
摄氧量(l/min)	0.985**
CO_2 呼出量(l/min)	0.980**
通气量(l/min)	0.973**
能量消耗(kcal/min)	0.986**

注: ** ICC 系数有非常显著的统计学差异($P < 0.01$)。

3.6　平板运动跑台测试和场地测试对于测量指标的 Bland-Altman 一致性检验

本研究使用 Bland-Altman 法[7] 对平板运动跑台测试和场地测试的摄氧量和能量消耗进行一致性分析, 以两组指标的平均值作为 X 轴, 两组指标的差值作为 Y 值, 图中分别使用实线和两条虚线标记出 Y 轴的均值和 95% 的置信区间(Mean ± 1.96× SD), 越多的点落在置信区间内, 差值均数越接近 0, 则一致性越好。图 6~ 图 9 中, 绝大多数的测试指标差值落在 95% 的置信区间内, 表明其测量结果的差异为可被接受的, 两种测量方法的一致性较好。

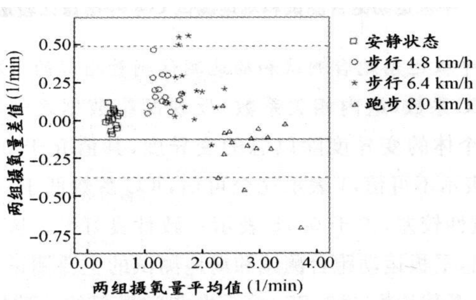


图 6　平板运动跑台测试和场地测试摄氧量的 Bland-Altman 散点图

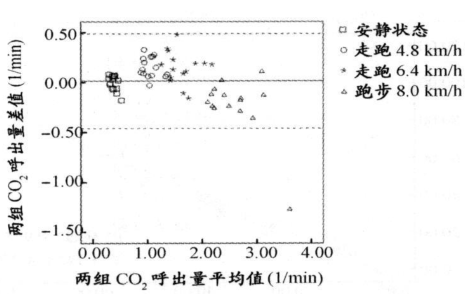


图 7　平板运动跑台测试和场地测试 CO_2 呼出量的 Bland-Altman 散点图

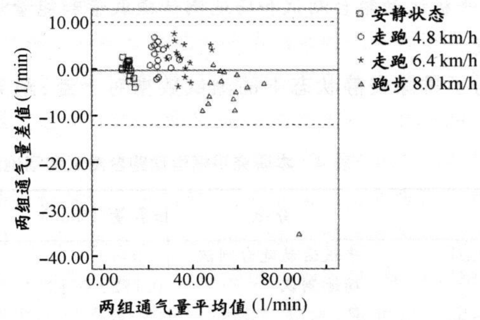


图 8　平板运动跑台测试和场地测试通气量的 Bland-Altman 散点图

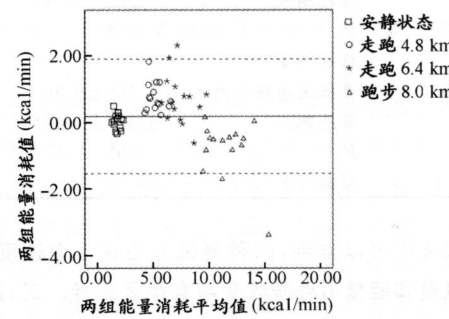


图 9　平板运动跑台测试和场地测试能量消耗值的 Bland-Altman 散点图

4　讨论

走、跑不仅是人们进行身体活动和运动的基本动作, 而且还是最常见、最重要的身体锻炼活动方法。准确测量走、跑过程中的能量消耗非常重要, 但使用平板运动跑台测试和场地测试存在一定差异。本研究选用了 3 个常用的走、跑速度 4.8 km/h(正常速度走)、6.4 km/h(快速走)和 8.0 km/h(慢跑), 主要考虑到: 一是, 能够代表日常走、跑活动的典型强度; 二是, 方便与以往研究结果相比较, 特别是能与《身体活动纲要》[4] 推荐值比较, 进而为评价我国人群的能量消耗提供参考。

受试者以 4.8 km/h 和 6.4 km/h 的速度走、跑时, 场地测试的摄氧量明显低于平板运动跑台测试 10% 以上, 且心率和能量消耗均明显降低, 排除受试者安静状态下的摄氧量和能量消耗干扰, 其净改变仍然有同样的改变, 其主要原因是由于平板运动跑台和场地测试的运动方式不同, 肌肉动员模式有所改变[14]。平板运动跑台走、跑和场地走、跑存在步态差异[26,13], 同样速度下两种走、跑方式的地面反应力和步态学都有所差别[27,10], 可能会影响能量消耗的测量。平板运动跑台走、跑中步频加快、步幅变小、步宽增加、双脚支撑时间缩短等, 提示了其不舒适和不稳定性导致了机体运动过程中摄氧量和能量消耗增加。同时, 肌电图的改变也提示场地行走时肌肉氧化模式可能更加经济有效, 而平板运动跑台走、跑时肌肉氧化的过程需要一定的适应期[9]。因此, 场地测试时受试者肌肉氧化能力更加经济有效, 直接导致场地测试的摄氧量和能量消耗低于平板运动跑台测试。

另外，本研究中平板运动跑台测试在先，受试者为首次接触平板运动跑台，一定程度上存在新奇和不适应感。对于普通人群而言，平板运动跑台是一个新事物。即使是对于经常使用平板运动跑台进行训练和测试的运动员来说，尽管他们已经对平板运动跑台产生了适应，但比赛的成绩仍然接近于场地测试成绩而非平板运动跑台测试成绩[1]。任何轻微的活动都可以提高机体的能量代谢，尤其普通人群在平板运动跑台走、跑时，由于走、跑方式的不熟练，除了可能出现的紧张、节奏加快和步幅缩短之外，还有可能会增加一些多余的走、跑动作，如摆臂幅度增加、肩关节僵硬、肌肉紧张等，这些都是机体能量消耗增加的因素。

但是，当走、跑速度为 8.0 km/h 时，场地测试摄氧量却高于平板运动跑台测试数值 7%，虽然摄氧量的增加无统计学意义，但摄氧量/体重和摄氧量/去脂体重的改变却存在非常显著的差异。绝对摄氧量和相对摄氧量变化的不同步可归咎于受试者的体重变异较大，但排除安静状态下的摄氧量和能量消耗干扰后，场地测试各项指标的增加更加明显(表 4)。提示，随着走、跑速度的增加，工作负荷克服了平板运动跑台上走、跑的紧张和不适，此时跑台有一定的助力作用。当受试者走、跑速度较低时，为脚跟先着地；而当8.0 km/h时，受试者为脚尖先着地[3]。随着跑台传送带速度的增加，同时增加了受试者双脚尖后蹬的力量，此时跑台运动的助力作用大于带来的紧张不适，因此，受试者能量消耗低于场地测试。另外，跑台测试和场地测试之间还存在空气阻力的问题，走、跑速度越高，空气阻力逐渐增加，机体需要消耗更多的氧气和能量完成同样的速度[15,24,25]。但本研究为室内进行，且研究中采用的跑速未达到快速的程度，因此可以忽略空气阻力造成的影响。

走、跑速度为 8.0 km/h 时，场地测试摄氧量和能量消耗高于平板运动跑台测试的可能原因有：第一，有研究指出，"自选速度"[20]或"同样用力程度"[9]走、跑时，场地测试的心率和最大跑速高于平板运动跑台测试；100 m 冲刺跑时虽然受试者在平板运动跑台和场地走、跑时都可自由发力，但场地走、跑的速度和成绩仍然好于平板运动跑台走、跑[18]；提示机体在场地低速或中速跑步时容易加快速度，导致与平板运动跑台测试相比摄氧量有所增加。对于受试者来说，8.0 km/h 的速度为慢跑，受试者可能会不由自主的出现用力和加快速度的现象。第二，虽然场地测试时受试者根据节奏和标志物严格控制跑速，且研究人员对其走、跑过程进行全程监督，但仍不能完全免除受试者速度不均匀、出现赶不上节奏或超过节奏的现象。以上究竟是哪部分原因导致场地走、跑的能量消耗大于平板运动跑台测试，还需要进一步的研究。

对两种测试方法进行评价时，直线相关是反映方法学评价的重要指标之一[28]。本研究对平板运动跑台和场地两种不同的测试方法测得主要指标进行直线相关分析(图 2～图 5)，以平板运动跑台测试的测试数据为自变量 X，场地测试的测试数据为因变量 Y，回归方程 $Y = aX + b$ 表现两组数据的线性趋势，方程式中 a 为斜率，b 为截距。图 2～图 5 显示两组数据明显的线性相关关系，且回归方程中的斜率和截距均有显著的统计学差异，说明两组测试数据之间的相关性。在直线相关分析中，根据相关系数 R^2 可对回归方程进行粗略估计，如 $R^2 \geq 0.95$ 则说明 X 取值范围合适，直线回归的斜率和截距可靠；如 $R^2 < 0.95$ 则应再多扩大数据范围或 X 取值范围不合适，回归统计的斜率和截距不能用来估计新方法带来的系统误差。本研究中摄氧量($R^2 = 0.95$)和能量消耗值($R^2 = 0.955$)的相关系数满足 ≥0.95 的条件，表明两个直线回归方程中 X 取值范围合适，直线回归的斜率和截距可靠，可用来预测平板运动跑台测试和场地测试之间的系统误差。

随着便携式气体代谢仪的不断更新，很多身体活动的能量消耗测定逐渐从实验室转到场地测试，对于一些活动来说，由于场地测试与实际活动相接近，而优于实验室测试，但究竟与平板运动跑台测试结果相比较一致性如何尚且未知。配对 t 检验主要检验的是两测量方法的系统误差是否有差别，即对两测量结果的系统误差敏感，但不能兼顾随机误差，因此，其本质是对"差异"的检验，而非对"一致"的检验[6]。国外很多研究采用 ICC 组内相关系数和 Bland-Altman 法评价两种测量方法中定量数据结果的一致性[7,29,8]，在考虑了随机误差的同时，也考虑了系统误差对于一致性的影响，因此，本研究也使用了这两个指标对场地测试与平板运动跑台测试进行了一致性评价。走、跑时两组之间气体代谢各项指标使用配对 t 检验差异明显，但 ICC 系数显示有良好的一致性(0.973～0.986)。另一个指标 Bland-Altman 法计算了两种测量结果的一致性界限，以测量结果的差值是否可被接受为依据，得出是否具有一致性的结论，在评价一致性方面具有独特的优势[15,17]。图 6～图 9 的散点图显示，测试指标的绝大多数差值落在置信空间内，表明其测量结果的差异为可被接受的，体现了平板运动跑台测试和场地测试数据的一致性。

本研究有两个局限。其一，研究设计侧重于对跑台与非跑台的差别进行研究，且为尽量减少室内、外环境和空气阻力的影响，选择了室内场地测试与跑台测试进行比较，但忽略了室内和室外地面的区别。此外，引用的文献研究中较多的是室外与跑台走、跑的对比，可能会对研究的分析造成一定影响。其二，两种测试方法的推导公式虽然相关系数较高($R^2 \geq 0.95$)，但由于样本量较少，可能会导致推算数据出现误差。因此，还需要进一步增加样本量对摄氧量和能量消耗两个推导公式进行验证。

5 结论

1. 相同速度下平板运动跑台走、跑和场地走、跑的能量

消耗差异显著, 只有直接测量场地走、跑的能量消耗才能反映日常生活中和体育健身活动中走、跑运动的真实状况。

2 应用直线回归分析建立了平板运动跑台测试和场地测试两种方法之间的转换推导公式, 根据跑台测试结果可推算场地测试耗氧量和能量消耗, 但由于样本量较少, 该公式还需要进一步增加样本量进行验证。

参考文献:

[1] 陈晓荣, 李可基. 我国成人步行和慢跑基本特征与代谢当量初探 [J]. 营养学报, 2010, 32(5): 433-437.

[2] 刘健敏, 李颜, 杨晓光. 应用 K4b^2 心肺功能测定仪对日常体力活动能量消耗的测定 [J]. 科学技术与工程, 2010,(5): 1215-1218.

[3] 王人成, 朱德有, 莫明军, 等. 行走和跑步两种步态模式的实验分析[J]. 中国康复医学杂志, 2002, 17(4): 233-235.

[4] AINSWORTH B E, HASKELL W L, WHITT M C, *et al*. Compendium of physical activities: an update of activity codes and MET intensities [J]. Med Sci Sports Exe, 2000, 32(9 Suppl): S498-504.

[5] BARTKO J J. The intraclass correlation coefficient as a measure of reliability [J]. Psychol Rep, 1966, 19(1): 3-11.

[6] BEDARD M, MARTIN N J, KRUEGER P, *et al*. Assessing reproducibility of data obtained with instruments based on continuous measurements [J]. Exp Aging Res, 2000, 26(4): 353-365.

[7] BLAND J M, ALTMAN D G. Statistical methods for assessing agreement between two methods of clinical measurement [J]. Lancet, 1986, 1(8476): 307-310.

[8] BLESSINGER J, SAWYER B, DAVIS C, *et al*. Reliability of the VmaxST portable metabolic measurement system [J]. Int J Sports Med, 2009, 30(1): 22-26.

[9] CEI R, HASSMEN P. Self-monitored exercise at three different RPE intensities in treadmill vs field running [J]. Med Sci Sports Exe, 1991, 23(6): 732-738.

[10] DINGWELL J B, CUSUMANO J P, CAVANAGH P R, *et al*. Local dynamic stability versus kinematic variability of continuous overground and treadmill walking [J]. J Biomech Eng, 2001, 123(1): 27-32.

[11] KRANENBRUG K J, SMITH D J. Comparison of critical speed determined from track running and treadmill tests in elite runners [J]. Med Sci Sports Exe, 1996, 28(5): 614-618.

[12] MACFARLANE D J. Automated metabolic gas analysis systems: a review [J]. Sports Med, 2001, 31(12): 841-861.

[13] MARSH A P, KATULA J A, PACCHIA C F, *et al*. Effect of treadmill and overground walking on function and attitudes in older adults [J]. Med Sci Sports Exe, 2006, 38(6): 1157-1164.

[14] MCMAHON T A, GREENE P R. The influence of track compliance on running [J]. J Biomech, 1979, 12(12): 893-904.

[15] MCMIKEN D F, DANIELS J T. Aerobic requirements and maximum aerobic power in treadmill and track running [J]. Med Sci Sports, 1976, 8(1): 14-17.

[16] MEYER T, WELTER J P, SCHARHAG J, *et al*. Maximal oxygen uptake during field running does not exceed that measured during treadmill exercise [J]. Eur J Appl Physiol, 2003, 88(4-5): 387-389.

[17] MITCHELL H, WHALEY P, FACSM. ACSM's Guidelines for Exercise Testing and Prescription (Seventh Edition) [M]. Baltimore (U.S.): Lippincott Williams & Wilkins, 2006: 148-149.

[18] MORIN J B, SEVE P. Sprint running performance: comparison between treadmill and field conditions [J]. Eur J Appl Physiol, 2011, 6(1): 9-16.

[19] MURRAY M P, SPURR G B, SEPIC S B, *et al*. Treadmill vs. floor walking: kinematics, electromyogram, and heart rate [J]. J Appl Physiol, 1985, 59(1): 87-91.

[20] NUMMELA A, HAMALAINEN I, RUSKO H. Comparison of maximal anaerobic running tests on a treadmill and track [J]. J Sports Sci, 2007, 25(1): 87-96.

[21] PARVATANENI K, PLOEG L, OLNEY S J, *et al*. Kinematic, kinetic and metabolic parameters of treadmill versus overground walking in healthy older adults [J]. Clin Biomech (Bristol, Avon), 2009, 24(1): 95-100.

[22] PASSMORE R, THOMSON J G, WAMOCK G M, *et al*. A balance sheet of the estimation of energy intake and energy expenditure as measured by indirect calorimetry, using the Kofranyi-Michaelis calorimeter [J]. Br J Nutr, 1952, 6(3): 253-264.

[23] PASSMORE R, DURNIN J V. Human energy expenditur [J]. Physiol Rev, 1955, 35(4): 801-840.

[24] PUGH L G. Oxygen intake in track and treadmill running with observations on the effect of air resistance [J]. J Physiol, 1970, 207(3): 823-835.

[25] PUGH L G. The influence of wind resistance in running and walking and the mechanical efficiency of work against horizontal or vertical forces [J]. J Physiol, 1971, 213(2): 255-276.

[26] SIMONSICK E M, MONTGOMERY P S, NEWMAN A B, *et al*. Measuring fitness in healthy older adults: the Health ABC Long Distance Corridor Walk [J]. J Am Geriatr Soc, 2001, 49(11): 1544-1548.

[27] STOLZE H, KUHTZ-BUSCHBECK J P, MONDWURF C, *et al*. Gait analysis during treadmill and overground locomotion in children and adults [J]. Electroencephalogr Clin Neurophysiol, 1997, 105(6): 490-497.

[28] THOLEN D W. Evaluation of linearity in the clinical laboratory [J]. Arch Pathol Lab Med, 2004, 128(10): 1078; author reply 1078.

[29] VOGLER A J, RICE A J, GORE C J. Validity and reliability of the Cortex MetaMax3B portable metabolic system [J]. J Sports Sci, 28(7): 733-742.

[30] ZENI A I, HOFFMAN M D, CLIFFORD P S. Energy expenditure with indoor exercise machines [J]. JAMA, 1996, 275(18): 1424-1427.

Step rate-determined walking intensity and walking recommendation in Chinese young adults

Journal:	*BMJ Open*
Manuscript ID:	bmjopen-2012-001801.R1
Article Type:	Research
Date Submitted by the Author:	19-Oct-2012
Complete List of Authors:	Wang, Huan; China Institution of Sports Science, mass sport zhang, Yanfeng; China Institute of Sport Science, mass sports XU, Liangliang; Shanghai Institute of Sport Science, , Center of Physical Fitness and Health Jiang, Chongmin; China Institute of Sport Science, mass sports
Primary Subject Heading:	Sports and exercise medicine
Secondary Subject Heading:	Public health
Keywords:	SPORTS MEDICINE, PUBLIC HEALTH, STATISTICS & RESEARCH METHODS

Step rate-determined walking intensity and walking recommendation in Chinese young adults

Wang Huan[1], Zhang Yan-feng[1], Xu Liang-liang[2] ,Jiang Chong-min[1]

1. China Institute of Sport Science, Department of Mass Sports, Beijing 100061, China;
2. Shanghai Institute of Sport Science, Center of Physical Fitness and Health, Shanghai 200030, China

Corresponding author
Wang Huan, China Institute of Sport Science, Department of Mass Sports, Beijing 100061, China.
Tel：(8610) 87182583
Fax: (8610) 67103872
Email:huanwang55@yahoo.com

Key Words
Walking, Step rate, Energy expenditure, Physical activity

Words count： 2776

ABSTRACT

Purpose There is lack of data on the physiological characteristics of over ground walking and walking recommendations for Chinese young adult. The purpose of the study is to measure walking-related energy expenditure during field testing, to identify step-rate cut point associated with moderate and vigorous intensity, and to translate physical activity (PA) guidelines into walking goals for Chinese young adults.

Design cross sectional analytic study

Setting two communities from Beijing and Shanghai in China

Participants A sample of 226 Chinese adults (117 men, 109 women) with a mean age of 21.7 (±0.2) years, volunteered to participate in the study. All Participants were recreationally active without orthopedic limitations, free of chronic diseases, not taking any medications that affect metabolism, and non-smokers.

Outcome measures All the participants completed four 6-minute incremental over ground walking at different speeds of 3.8km/h,4.8 km/h,5.6 km and 6.4 km/h, respectively. Indirect calorimeter was used to measure energy expenditure at each speed. Receiver operating characteristic (ROC) curves were used to determine the step-rate cut points associated with moderate and vigorous intensity activity.

Results At the same walking speed，step counts per minute were higher in women than in men. No significant differences were found in VO_2 per weight（$ml·kg^{-1}·min^{-1}$）between women and men. Step-rate cut point associated with walking at 3METs and 6METs were 105 $step·min^{-1}$and 130 $step·min^{-1}$when analyzing men and women together. There were slight differences on the cut points between women and men if data were analyzed separately.

Conclusions In order to meet PA guidelines, Chinese young adult should walk 30 minutes

with at least 105 step·min^{-1}, or 3,150 steps or 2 kilometers with the same step-rate per day. Walking at a higher speed of 130 step·min^{-1} might provide additional health benefit.

INTRODUCTION

Engaging in adequate amounts of physical activity has positive effect on energy balance, weight control, cardio-respiratory fitness and other health benefits**[1-5]**. It has been recommended that all adults perform at least 30 min of moderate-intensity aerobic activity 5 day each week to achieve health benefits of exercise, and physical activity of greater intensity or of longer duration can promote additional benefits to health**[3]**. Among all the activities, walking is regarded by public as the most common exercise**[6]**. Obviously it is a meaningful research area to explore how much walking are enough to meet Physical Activity Guideline.

Some steps-based walking recommendation is developed by researchers**[7-10]**. The most widely recognized step recommendation is to accumulate 10,000 steps per day. However, the goal of 10,000 steps per day is based on very limited evidence, may be unrealistic for many people**[11]**. In addition, it has not incorporated the activity intensity. Intensity is an important index of physical activity recommendations due to health benefits are depending on the intensity of activity**[12]**.

Step rate (step·min^{-1}) is one of the important parameters of walking gait and can be used to identify intensity in free-living walking**[13]**. In addition, step rate, as a simple indicator of ambulatory behavior, can be captured easily. More specific, if walking duration and step numbers are known, intensity (step rate) can be calculated, therefore, certain specific cut points (step·min^{-1}) can be used to indicate intensity categories. Recently, studies have been conducted to identify step rates that correspond to intensity classifications**[14-15]**. These studies have found that walking at a pace of 100step·min^{-1} corresponds to moderate intensity and this finding may be used to

promote public health recommendation of accumulating 3000 steps in 30 minutes to meet physical activity guidelines. Although these studies provide insightful data, there are limitations in their research methods. First, step rate cut points were obtained under controlled laboratory conditions, such as treadmill walking, which may differ from realistic activities (such as ground walking). Second, the small sample sizes from these previous studies limit its generalizability to larger population.

Physiological responses of physical activity are dependent on the biological characteristics of the study population, such as race, height, weight, gender, and age**[16]**. Most of current walking recommendation studies were based on Westerners**[17,18]**. No studies have been conducted in Chinese sample. It is well-known that China is experiencing rapid economic growth. In China, family owned vehicle is getting more popular; therefore, more young people are driving instead of walking for daily activities. An evidence-based walking recommendation is in critical need for Chinese adults.

The purposes of this study were(1)to identify step rate threshold associated with moderate and vigorous intensity activity for Chinese young adult, and(2)to translate PA guidelines into walking recommendation for Chinese young adults.

METHODS

Participants

A community-based sample of 226 Chinese adults (117 men, 109 women) with a mean age of 21.7 (±0.2) years, volunteered to participate in the study. All Participants were recreationally active without orthopedic limitations, free of chronic diseases, not taking any medications that affect metabolism, and non-smokers. This study was reviewed and approved by China Institute of Sport Science Institutional Review Board. Participants provided written informed consent to participate in the study.

Walking Testing

For walking test, we applied the previously established method to control over ground walking speed[19]. Briefly, an indoor room at room temperature (22.5±0.7□), well ventilated, and with concrete floor was used. An area of 15m×10m rectangular field (circumference of 50m) was marked. Markers were placed on the edges (4 sides) of the field with 5m apart and used as tracking indicators while the subjects were walking along the edges. Participants were required to perform 4 walking tests at four different walking speeds 3.8km/h, 4.8km/h, 5.6km, and 6.4km/h for 6 minutes, respectively. During the test, participants were reminded of remaining natural gait, looking straight, and moving from one marker to the next. They took 10 minutes rest before the test, and 5 minutes rest between each test. It was proved that subjects could easily maintain the pre-set walking speed by following the instructions and markers on the ground, and also keep the normal, relaxed walking manner[19].

Energy expenditure was measured by the Cortex MetaMax 3B metabolic analyzer

(German). Steady-state VO_2 was recorded as an average of the last 2 minutes of each exercise bout. METs were calculated by dividing steady-state VO_2 by $3.5 ml \cdot ml^{-1} \cdot kg^{-1}$. Moderate intensity was defined as 3.00–5.99METs, while vigorous intensity for 6.00–8.99METs.

After participants reached the steady state at each walking speed level (after 3 minutes), the steps per min were recorded by a trained staff through hand counter. Numbers of steps were recorded twice at each walking speed, and the average value was calculated.

Height and Weight Measurement

Height was measured without shoes to the nearest 0.1centimeter using a calibrated electronic height meter. Weight was measured in light clothing and without shoes to the nearest 0.1 kg using a calibrated electronic scale. BMI was calculated as weight in kilograms (kg) divided by height in meters squared.

Statistics analysis

Descriptive statistics were expressed as mean ± SD for the physiological variables under each walking speed. Gender differences were tested using independent t-tests.

Step-rate cut points were determined using receiver operating characteristic (ROC) curves. ROC curves were developed to examine optimal cut points in terms of sensitivity (correctly identifying participants who were at moderate intensity or vigorous intensity activity) and specificity (correctly identifying those who were not at moderate intensity or vigorous intensity activity).

An alpha level of 0.05 was used to determine significance for all statistics analysis.

All analyses were performed using SPSS16.0.

Results

The characteristics of the study participants are presented in Table 1. Comparison between men and women regarding measured variables at each walking speed in men and women is presented in Table 2. The heart rate and VO_2 ($L \cdot min^{-1}$) in men were significantly higher ($P<0.05$) than those in women at the same speed of walking. When VO_2 was adjusted for body mass, the sex effect disappeared. No significant differences were found in VO_2 per kg between women and men across different speeds.

Table 1. Participant characteristics by gender

Variable (Mean±SD)	**Women**	**Men**	**All**
n	109	117	226
Age(yr)	21.8±2.0	21.7±2.0	21.7±2.0
Height(cm)	166.2±5.4	175.7±5.0	170.1±6.1
Weight(kg)	59.6±8.3	69.1±8.4	64.5±9.6
BMI (kg/m^2)	21.5±2.5	22.4±2.4	22.0±2.5

BMI, body mass index; SD, standard deviation.

Table 2 also shows that under the same walking speed, the step rate was different among participants. At the same walking speed, step rate was higher in women than in men. Although higher step rate consumes more EE, there is no significant relationship between VO_2 and step rate within each speed (Pearson Correlation coefficient r=0.28). The step rate increased accordingly while the walking speed increased in both men and women. There was significant correlation between step rate and VO_2（Pearson Correlation coefficient r=0.73）.

Table 2 Comparison between men and women regarding measured variables at each walking speed

		Men		Women		P Value
		Mean	SD	Mean	SD	
3.8km/h	HR	83.2	10.3	87.8	9.1	0.02
	VO_2(ml·kg^{-1}·min^{-1})	10.47	0.67	10.32	0.69	0.25
	VO_2(L·min^{-1})	0.72	0.05	0.61	0.04	＜0.00
	METs	2.93	0.21	2.91	0.19	0.78
	Step rate(step·min^{-1})	95.71	3.12	97.46	3.36	＜0.00
4.8km/h	HR	93.3	11.1	102.3	9.6	＜0.00
	VO_2(ml·kg^{-1}·min^{-1})	13.94	1.41	13.58	1.63	0.82
	VO_2(L·min^{-1})	0.97	0.12	0.82	0.14	＜0.00
	METs	4.02	0.45	3.96	0.61	0.40
	Step rate(step·min^{-1})	113.06	6.25	115.68	5.85	0.001
5.6km/h	HR	102.2	11.6	113.4	11.0	＜0.00
	VO_2(ml·kg^{-1}·min^{-1})	15.99	1.72	15.94	1.86	0.84
	VO_2(L·min^{-1})	1.10	0.14	0.95	0.18	＜0.00
	METs	4.58	0.50	4.58	0.71	0.95
	Step rate(step·min^{-1})	119.61	6.22	123.01	6.93	＜0.00
6.4km/h	HR	114.2	14.3	126.9	12.9	＜0.00
	VO_2(ml·kg^{-1}·min^{-1})	19.07	2.29	19.02	2.66	0.88
	VO_2(L·min^{-1})	1.32	0.19	1.14	0.21	＜0.00
	METs	5.46	0.67	5.50	0.93	0. 74
	Step rate(step·min^{-1})	126.01	7.02	131.00	8.40	＜0.00

HR, heart rate; METs, metabolic equivalent, divide VO_2 by 3.5ml·ml^{-1}·kg^{-1};

There were significant differences between MET value calculated from measured VO_2 with recommended value from PA Compendium**[20].** The measured METs was significantly higher than recommended value at 4.8km/h, 5.6km/h and 6.4km/h, respectively (Figure 1).

The different cut point regarding step rate among men and women is shown in Table 3. According to MPA and VPA identified from indirect calerometry, ROC-curve suggested that the optimal step-rate cut point was 105 step·min^{-1} for MPA with 85% sensitivity and 74% specificity. For the VPA cut-point, the optimal step-rate was 130 step·min^{-1} with 96% sensitivity and 67% specificity. Women had slightly higher cut point than men.

Table 3 Step rate(step·min^{-1}) cut-points associated with MPA and VPA in women and men from the present study and other literatures

Intensity classification		The present study (ROC analysis)	Simon J et al [14]		Tudor et al [15]	Beets MW et al [26]	Rowe DA et al [27]
			Linear regression analysis	ROC analysis			
MPA (3METs)	All	105	89	107	100	100 (85-111)*	100 (90-113)*
	Men	104	92	102	96		
	Women	107	91	115	107		
VPA (6METs)	All	130	ND	ND	130	ND	ND
	Men	127			125		
	Women	137			136		

ROC, receiver operating characteristic curves used to determine the step-rate cut points

ND, no data provided

*The range of step rate based on difference of leg length[26] and height[27]

Discussion:

The main purpose of this study was to use indirect calorimeter to identify a step-rate cut-point associated with activity intensity in a field environment. To our knowledge, this was the first attempt to establish a walking target for Chinese people. We identified the optimal step-rate cut point was 105step·min^{-1} for MPA and 130step·min^{-1} for VPA. Applying cut-point for MPA to calculate the walking steps and distance taken to meet PA guidelines, 30minutes of moderate-intensity activity corresponds to 3,100 steps in young men and 3,200 steps in young women, or roughly 3150 steps for both. If steps are converted to walking distance, it is about 2 km.

We tested 4 different walking speeds in this study. Three of them were significantly corresponded with PA Compendium**[20]**.When compared with EE reference from PA Compendium, the EE measured from our study was higher for three walking speeds. Previous studies showed inconsistent results when comparing measured EE with compendium reference. Some reported higher value**[21]**, others reported lower value**[22-23]**. The inconsistency might be due to difference in sample characteristics, testing methods, and test environment **[21,24,25]**. Therefore, it is not proper to perform complete result comparisons for different test condition. For the current study test setting might be a contributor to the difference. We conducted the walking test in a field setting, not on a treadmill. Our previous study found that walking-related energy expenditure in the field was different from treadmill testing**[19]**. However, the intensity of these 3 walking speeds in present study was between 4.0 and 5.5 MET, which was in the range of 3-6 MET as moderate intensity identified by PA Compendium.

Objective measurement method and larger sample size allowed this study to establish the step rate cut point related to intensity (METs) as a minimum threshold for MPA walking and VPA walking. To date, four other studies have used indirect calorimeter to validate a step-rate cut point associated with moderate or vigorous intensity walking. Simon J measured the step rate and intensity on treadmill**[14]**. Different cut-points were obtained from different statistical method, and the author concluded walking at 100 step·min^{-1}on ground level would meet the moderate-intensity walking recommendation. Tudor-Locke and his colleagues determined that 96 and 107 step·min^{-1} as the minimum threshold for moderate-intensity walking, and 125 and 136 step·min^{-1}for vigorous-intensity for young men and women**[15]**. The two other studies supported the 100 step·min^{-1}as moderate-intensity walking cadence while emphasized inter-individual variation of step rate were apparent due to anthropometric differences such as height and leg length**[26,27]**. Our finding corresponded closely with these previous studies, although our cut-point was slightly higher. The similar findings of these studies are encouraging given the differences between the sample characteristics and methodologies, which offer some evidence that will support the development of a consensus step rate recommendation for the people in different countries.

In addition, we found that there was significant difference of step rate between young men and women at the same walking speed, therefore it seems proper to have different cut point recommendation for men and women separately. The gender differences in the mean step rate may be caused by differences in height and leg-length. At the same walking speed, female's step frequency is higher than male due to shorter height and shorter lower limb. However, since the difference of step rate between men and women was less than 10 steps per min, considering the needs to establish the walking recommendation in a relatively simple way, we think that single step rate recommendation would be more effective in physical activity promotion and intervention application. Therefore, we suggest 105 step·min^{-1} and 130 step·min^{-1} cut-points to be corresponded to MPA and VPA. However, if the recommendations of individualized step rate would be developed in the future, physical differences such as height, leg length and gender should also be considered.

In order to associate our step rate cut point with PA guideline**[3]**, the minimum walking steps of 3,150 steps daily for MPA were considered based on our study results. It should be emphasized that 3,150 steps need to be taken above the basic number of daily steps**[15]**. Recent study has reported the daily walking steps goal for American people is 8000 steps, derived from accelerometer data**[10]**, but earlier study reported 10000 steps**[8]**. Since people have different physical activity patterns, it is difficult to establish consistent total number of walking steps for everyone. Moreover, there is not a comprehensive walking recommendation if only walking steps is involved but not the intensity. Therefore, it is practical and useful to provide a general suggestion that how many extra steps individual needs to take above the daily activities and how fast to walk for health promotion. Specially, Chinese young adult should walk at least 30 minutes with a minimal 105 steps/min, or 3150 steps or 2 kilometers with the same step rate daily to meet PA guidelines. They will perform vigorous-intensity activity if 130 step·min^{-1} is reached and this will provide more health benefit.

China is experiencing rapid economic growth. With the increase of private car ownership and the reduction of the intensity of work, a rapid decrease of physical activity levels of Chinese people has caused widespread concern. Data from 2007 China Physical Activity and Exercise

Survey showed that the proportion of young people aged 20-29 years to participate in regular exercise is the lowest among survey population aged 16-70 years old, with only 6.2 percent[**30**]. Walking is the most common and easy exercise. Walking above the certain speed can improve the health of people[**31**]. Therefore, a walking recommendation built on scientific evidence for Chinese young adults is a meaningful step to help them promote the physical activity levels.

One strength of the present study was large sample size and EE measurement in field settings, which provide sufficient power to identify the step rate cut- points accurately. Another strength was to provide Chinese young adults a walking recommendation in form of relative flexible assistive tool. People can achieve their own exercise goal by using different calculations, such as step rate, walking during, total walking steps, and/or walking distance. There were a number of limitations in this study. The first limitation was the small age range of young participants. It was known that gait and energy expenditure will be different between older and young individuals**[28]**. At the same walking speed, older people will have the gait of shorter step length and faster step rate**[29]**.Therefore, the cut point established might not be suitable for older population. The second limitation was the use of a constant (3.5 ml·kg^{-1}·min^{-1}) as an estimated value of resting energy expenditure, instead of a direct measurement for calculating METs. Although the use of this constant is widely accepted in the scientific literature, it is likely to overestimate resting-energy expenditure at the individual level**[23-24]**. Then, the step rate cut point developed by the estimated value of MET might be overestimated. The third of limitation was lack of cross-validation. Considering the data collected under the current controlled environment may be different from the real environment, future study should focus on establishing the validity of the current cut points through independent validation studies in real-life field walking.

Conclusion:

The step rate cut-points corresponding to activity intensity categories (in terms of MET levels) have been set up by this study. It could be useful for recommending appropriate amounts of walking exercise to meet PA guidelines for Chinese young adults. The findings from this study indicate that Chinese young adult should walk at least 30 minutes with a minimal 105 step·min^{-1}, or 3150 steps with the same step rate daily to meet PA guidelines. There were slight differences on step-rate threshold and minimal steps between women and men, so further specific step rate recommendations can be developed for different gender group.

What this study adds

1. This study shows that under the same walking speed, there was a small difference of EE due to different step rate among individuals. When the walking speed increased from 3.8km/h to 6.4 km/h, step rate and energy expenditure increased almost at the same rate.

2. This study also shows at the same walking speed, step rate was higher in women than in men, but the difference is less than 10 step•min^{-1}.

3. This study compares the data from Chinese young people's walking energy expenditure with other findings based on western participants and set up the walking recommendation for Chinese young people for the first time.

Contributors All authors were involved with the planning and designing of the study, as well as data collection. Wang Huan was responsible for the first draft of the manuscript, which was subsequently revised by all other authors.

Acknowledgements The authors thank the contribution of Dr Steven Blair and Dr Xue-mei Sui, who provided additional information for data analysis and careful modification for the text of this paper.

Competing interests None.

Project and Funding

National Key Technology Support Program（2006BAK33B03）was funded by Ministry of Science and Technology (MST) in China

REFERENCES

1. Caspersen CJ, Fulton JE. Epidemiology of walking and type 2 diabetes. *Med Sci Sports Exerc* 2008;**40**(7suppl):S519–28.

2. Eyler AA, Brownson RC, Bacak SJ, et al. The epidemiology of walking for physical activity in the United States. *Med Sci Sports Exerc* 2003;**35**:1529–36.

3. Haskell WL, Lee IM, Pate RR, et al. Physical activity and public health: updated recommendation for adults from the American College of Sports Medicine and the American Heart Association. *Med Sci Sports Exerc* 2007;**39**:1423–1434.

4. Hamer M, Chida Y. Walking and primary prevention: a meta-analysis of prospective cohort studies. *Br J Sports Med* 2008;**42**:238–43.

5. Lee IM, Buchner DM. The importance of walking to public health. *Med Sci Sports Exerc 2008*;**40**(7 suppl):S512–8.

6. Workman JM, Armstrong BW. Metabolic cost of walking: equation and model. *J Appl Physiol* 1986;61(4):1369-1374.

7. Tudor-Locke C, Ainsworth BE, Thompson RW, et al. Comparison of pedometer and accelerometer measures of free-living physical activity. *Med Sci Sports Exerc* 2002;**34**: 2045–2051.

8. Tudor-Locke C, Bassett DR. How many steps/day are enough? Preliminary pedometer indices for public health *Sports Med* 2004;34: 1–8.

9. Tudor-Locke C, Hatano Y, Pangrazi RP, et al, Revisiting "how many steps are enough?" *Med Sci Sports Exerc* 2008;40:S537–S543.

10. Tudor-Locke C, Johnson WD, Katzmarzyk PT. Accelerometer-determined steps

per day in US adults. *Med Sci Sports Exerc* 2009;**41**: 1384–1391.

11. Wilde BE, Sidman CL, Corbin CB. A 10,000-step count as a physical activity target for sedentary women *Research Quarterly for Exercise and Sport* 2001; (72)4:411-414.
12. Pearce ME, Cunningham DA, Donner AP, et al. Energy cost of treadmill and floor walking at self-selected paces. *Eur J Appl Physiol Occup Physiol*. 1983;52(1):115-9.
13. Tudor-Locke C, Rowe DA. Using Cadence to Study Free-Living Ambulatory Behaviour. *Sports Medicine* 2012;**3**: 1-17.
14. Simon J Marshall, Susan SL, Karen MW, et al. Translating Physical Activity Recommendations into a Pedometer-Based Step Goal. *Am J Prev Med* 2009;**36**:410–415.
15. Tudor-Locke C, Sisson SB, Collova T, et al. Pedometer-determined step count guidelines for classifying walking intensity in a young ostensibly healthy population. *Can J Appl Physiol* 2005;**30**: 666-676.
16. Morris JN, Hardman AE. Walking to health. *Sports Med* 1997;**23**:306–32.
17. Bertram JE, Ruina A. Multiple Walking Speed-frequency Relations are Predicted by Constrained Optimization. *J Theor Biol* 2001;209:445-453.
18. Zarrugh MY, Radcliffe CW. Predicting Metabolic Cost of Level Walking. *Europ J Appl Physiol* 1978;38: 215-223.
19. Jiang Chongmin, Qiu Shumin, Wang Huan. Comparison of treadmill and field test for energy consumption during running and walking. *Sport Science(China)*

2010;7:30-37.

20. Ainsworth BE, Haskell WL, Whitt MC, et al. Compendium of physical activities: an update of activity codes and MET intensities. *Med Sci Sports Exerc* 2000;**32**(Suppl. 9):S498–51.

21. Anjos LA, Wahrlich V, Bossan FM, et al. Energy expenditure of walking at different intensities in Brazilian college women. *Clinical Nutrition* 2008; 27:121–125.

22. Byrne NM, Hills AP, Hunter GR, et al. Metabolic equivalent: one size does not fit all. *J Appl Physiol* 2005;**99**:1112–9.

23. Gunn SM, Brooks AG, Withers RT, et al. Determining energy expenditure during some household and garden tasks. *Med Sci Sports Exerc* 2002;**34**:895–902.

24. Gunn SM, van der Ploeg GE, Withers RT, et al. Measurement and prediction of household energy expenditure in males during household and garden tasks. *Eur J Appl Physiol* 2004;**91**:61–70.

25. HALL C, A FIGUEROA, B FERNHALL, et al. Energy Expenditure of Walking and Running: Comparison with Prediction Equations. *Med Sci Sports Exerc* 2004;**36**: 2128–2134.

26. Beets MW, Agiovlasitis S, Fahs CA, et al. Adjusting step count recommendations for anthropometric variations in leg length. *J Sci Med Sport* 2010; **13**:509-12.

27. Rowe DA, Welk GJ, Heil DP, et al. Stride rate recommendations for moderate intensity walking. *Med Sci Sports Exerc* 2011; **43**:312-318.

28. Demura S, Sohee S, Yamaji S. Sex and age differences of relationships among

stepping parameters for evaluating dynamic balance in the elderly. J Physiol Anthropol.2008; 27:207-15.

29. Cavagna GA, Franzetti P. The Determinants of the Step Frequency in Walking in Humans. J Physiol 1986; 373:235-242.

30. General Administration of sports of China. The 3rd National Mass Sports Status Investigation Report. Beijing:People's Sports Publishing House of China, 2010:44-45.

31. Liu Ailing, Hu Xiaoqi, Li Yanping. Modes of Transportation by Chinese Non-agriculture Employed Population. *Chin J Prev Contr Chron Dis* 2009;2:114-116.

FIGURE LEGEND

White column: Measured value

Black column: PA Compendium recommendation

Title：Comparison of the measured METs value and Compendium

(* significantly different (one-sample T Test) from Compendium value)

Step rate-determined walking intensity and walking recommendation in Chinese young adults

Wang Huan[1], Zhang Yan-feng[1], Xu Liang-liang[2] ,Jiang Chong-min[1]

1. China Institute of Sport Science, Department of Mass Sports, Beijing 100061, China;
2. Shanghai Institute of Sport Science, Center of Physical Fitness and Health, Shanghai 200030, China

Corresponding author
Wang Huan, China Institute of Sport Science, Department of Mass Sports, Beijing 100061, China.
Tel：(8610) 87182583
Fax: (8610) 67103872
Email:huanwang55@yahoo.com

Key Words
Walking, Step rate, Energy expenditure, Physical activity

Words count： 2776

ABSTRACT

Purpose There is lack of data on the physiological characteristics of over ground walking and walking recommendations for Chinese young adult. The purpose of the study is to measure walking-related energy expenditure during field testing, to identify step-rate cut point associated with moderate and vigorous intensity, and to translate physical activity (PA) guidelines into walking goals for Chinese young adults.

Design cross sectional analytic study

Setting two communities from Beijing and Shanghai in China

Participants A sample of 226 Chinese adults (117 men, 109 women) with a mean age of 21.7 (±0.2) years, volunteered to participate in the study. All Participants were recreationally active without orthopedic limitations, free of chronic diseases, not taking any medications that affect metabolism, and non-smokers.

Outcome measures All the participants completed four 6-minute incremental over ground walking at different speeds of 3.8km/h,4.8 km/h,5.6 km and 6.4 km/h, respectively. Indirect calorimeter was used to measure energy expenditure at each speed. Receiver operating characteristic (ROC) curves were used to determine the step-rate cut points associated with moderate and vigorous intensity activity.

Results At the same walking speed，step counts per minute were higher in women than in men. No significant differences were found in VO_2 per weight（$ml \cdot kg^{-1} \cdot min^{-1}$）between women and men. Step-rate cut point associated with walking at 3METs and 6METs were 105 $step \cdot min^{-1}$ and 130 $step \cdot min^{-1}$ when analyzing men and women together. There were slight differences on the cut points between women and men if data were analyzed separately.

Conclusions In order to meet PA guidelines, Chinese young adult should walk 30 minutes

with at least 105 step·min^{-1}, or 3,150 steps or 2 kilometers with the same step-rate per day. Walking at a higher speed of 130 step·min^{-1} might provide additional health benefit.

INTRODUCTION

Engaging in adequate amounts of physical activity has positive effect on energy balance, weight control, cardio-respiratory fitness and other health benefits**[1-5]**. It has been recommended that all adults perform at least 30 min of moderate-intensity aerobic activity 5 day each week to achieve health benefits of exercise, and physical activity of greater intensity or of longer duration can promote additional benefits to health**[3]**. Among all the activities, walking is regarded by public as the most common exercise**[6]**. Obviously it is a meaningful research area to explore how much walking are enough to meet Physical Activity Guideline.

Some steps-based walking recommendation is developed by researchers**[7-10]**. The most widely recognized step recommendation is to accumulate 10,000 steps per day. However, the goal of 10,000 steps per day is based on very limited evidence, may be unrealistic for many people**[11]**. In addition, it has not incorporated the activity intensity. Intensity is an important index of physical activity recommendations due to health benefits are depending on the intensity of activity**[12]**.

Step rate (step·min^{-1}) is one of the important parameters of walking gait and can be used to identify intensity in free-living walking**[13]**. In addition, step rate, as a simple indicator of ambulatory behavior, can be captured easily. More specific, if walking duration and step numbers are known, intensity (step rate) can be calculated, therefore, certain specific cut points (step·min^{-1}) can be used to indicate intensity categories. Recently, studies have been conducted to identify step rates that correspond to intensity classifications**[14-15]**. These studies have found that walking at a pace of 100step·min^{-1} corresponds to moderate intensity and this finding may be used to

promote public health recommendation of accumulating 3000 steps in 30 minutes to meet physical activity guidelines. Although these studies provide insightful data, there are limitations in their research methods. First, step rate cut points were obtained under controlled laboratory conditions, such as treadmill walking, which may differ from realistic activities (such as ground walking). Second, the small sample sizes from these previous studies limit its generalizability to larger population.

Physiological responses of physical activity are dependent on the biological characteristics of the study population, such as race, height, weight, gender, and age**[16]**. Most of current walking recommendation studies were based on Westerners**[17,18]**. No studies have been conducted in Chinese sample. It is well-known that China is experiencing rapid economic growth. In China, family owned vehicle is getting more popular; therefore, more young people are driving instead of walking for daily activities. An evidence-based walking recommendation is in critical need for Chinese adults.

The purposes of this study were(1)to identify step rate threshold associated with moderate and vigorous intensity activity for Chinese young adult, and(2)to translate PA guidelines into walking recommendation for Chinese young adults.

METHODS

Participants

A community-based sample of 226 Chinese adults (117 men, 109 women) with a mean age of 21.7 (±0.2) years, volunteered to participate in the study. All Participants were recreationally active without orthopedic limitations, free of chronic diseases, not taking any medications that affect metabolism, and non-smokers. This study was reviewed and approved by China Institute of Sport Science Institutional Review Board. Participants provided written informed consent to participate in the study.

Walking Testing

For walking test, we applied the previously established method to control over ground walking speed[19]. Briefly, an indoor room at room temperature (22.5±0.7□), well ventilated, and with concrete floor was used. An area of 15m×10m rectangular field (circumference of 50m) was marked. Markers were placed on the edges (4 sides) of the field with 5m apart and used as tracking indicators while the subjects were walking along the edges. Participants were required to perform 4 walking tests at four different walking speeds 3.8km/h, 4.8km/h, 5.6km, and 6.4km/h for 6 minutes, respectively. During the test, participants were reminded of remaining natural gait, looking straight, and moving from one marker to the next. They took 10 minutes rest before the test, and 5 minutes rest between each test. It was proved that subjects could easily maintain the pre-set walking speed by following the instructions and markers on the ground, and also keep the normal, relaxed walking manner[19].

Energy expenditure was measured by the Cortex MetaMax 3B metabolic analyzer

(German). Steady-state VO_2 was recorded as an average of the last 2 minutes of each exercise bout. METs were calculated by dividing steady-state VO_2 by $3.5 ml \cdot ml^{-1} \cdot kg^{-1}$. Moderate intensity was defined as 3.00–5.99METs, while vigorous intensity for 6.00–8.99METs.

After participants reached the steady state at each walking speed level (after 3 minutes), the steps per min were recorded by a trained staff through hand counter. Numbers of steps were recorded twice at each walking speed, and the average value was calculated.

Height and Weight Measurement

Height was measured without shoes to the nearest 0.1centimeter using a calibrated electronic height meter. Weight was measured in light clothing and without shoes to the nearest 0.1 kg using a calibrated electronic scale. BMI was calculated as weight in kilograms (kg) divided by height in meters squared.

Statistics analysis

Descriptive statistics were expressed as mean ± SD for the physiological variables under each walking speed. Gender differences were tested using independent t-tests.

Step-rate cut points were determined using receiver operating characteristic (ROC) curves. ROC curves were developed to examine optimal cut points in terms of sensitivity (correctly identifying participants who were at moderate intensity or vigorous intensity activity) and specificity (correctly identifying those who were not at moderate intensity or vigorous intensity activity).

An alpha level of 0.05 was used to determine significance for all statistics analysis.

All analyses were performed using SPSS16.0.

Results

The characteristics of the study participants are presented in Table 1. Comparison between men and women regarding measured variables at each walking speed in men and women is presented in Table 2. The heart rate and VO_2 ($L\cdot min^{-1}$) in men were significantly higher ($P<0.05$) than those in women at the same speed of walking. When VO_2 was adjusted for body mass, the sex effect disappeared. No significant differences were found in VO_2 per kg between women and men across different speeds.

Table 1. Participant characteristics by gender

Variable (Mean±SD)	Women	Men	All
n	109	117	226
Age(yr)	21.8±2.0	21.7±2.0	21.7±2.0
Height(cm)	166.2±5.4	175.7±5.0	170.1±6.1
Weight(kg)	59.6±8.3	69.1±8.4	64.5±9.6
BMI (kg/m^2)	21.5±2.5	22.4±2.4	22.0±2.5

BMI, body mass index; SD, standard deviation.

Table 2 also shows that under the same walking speed, the step rate was different among participants. At the same walking speed, step rate was higher in women than in men. Although higher step rate consumes more EE, there is no significant relationship between VO_2 and step rate within each speed (Pearson Correlation coefficient r=0.28). The step rate increased accordingly while the walking speed increased in both men and women. There was significant correlation between step rate and VO_2（Pearson Correlation coefficient r=0.73）.

Table 2 Comparison between men and women regarding measured variables at each walking speed

		Men		Women		P Value
		Mean	SD	Mean	SD	
3.8km/h	HR	83.2	10.3	87.8	9.1	0.02
	VO_2(ml·kg^{-1}·min^{-1})	10.47	0.67	10.32	0.69	0.25
	VO_2(L·min^{-1})	0.72	0.05	0.61	0.04	＜0.00
	METs	2.93	0.21	2.91	0.19	0.78
	Step rate(step·min^{-1})	95.71	3.12	97.46	3.36	＜0.00
4.8km/h	HR	93.3	11.1	102.3	9.6	＜0.00
	VO_2(ml·kg^{-1}·min^{-1})	13.94	1.41	13.58	1.63	0.82
	VO_2(L·min^{-1})	0.97	0.12	0.82	0.14	＜0.00
	METs	4.02	0.45	3.96	0.61	0.40
	Step rate(step·min^{-1})	113.06	6.25	115.68	5.85	0.001
5.6km/h	HR	102.2	11.6	113.4	11.0	＜0.00
	VO_2(ml·kg^{-1}·min^{-1})	15.99	1.72	15.94	1.86	0.84
	VO_2(L·min^{-1})	1.10	0.14	0.95	0.18	＜0.00
	METs	4.58	0.50	4.58	0.71	0.95
	Step rate(step·min^{-1})	119.61	6.22	123.01	6.93	＜0.00
6.4km/h	HR	114.2	14.3	126.9	12.9	＜0.00
	VO_2(ml·kg^{-1}·min^{-1})	19.07	2.29	19.02	2.66	0.88
	VO_2(L·min^{-1})	1.32	0.19	1.14	0.21	＜0.00
	METs	5.46	0.67	5.50	0.93	0. 74
	Step rate(step·min^{-1})	126.01	7.02	131.00	8.40	＜0.00

HR, heart rate; METs, metabolic equivalent, divide VO_2 by 3.5ml·ml^{-1}·kg^{-1};

There were significant differences between MET value calculated from measured VO_2 with recommended value from PA Compendium[20]. The measured METs was significantly higher than recommended value at 4.8km/h, 5.6km/h and 6.4km/h, respectively (Figure 1).

The different cut point regarding step rate among men and women is shown in Table 3. According to MPA and VPA identified from indirect calerometry, ROC-curve suggested that the optimal step-rate cut point was 105 step·min^{-1} for MPA with 85% sensitivity and 74% specificity. For the VPA cut-point, the optimal step-rate was 130 step·min^{-1} with 96% sensitivity and 67% specificity. Women had slightly higher cut point than men.

Table 3 Step rate(step·min^{-1}) cut-points associated with MPA and VPA in women and men from the present study and other literatures

Intensity classification		The present study (ROC analysis)	Simon J et al [14]		Tudor et al [15]	Beets MW et al [26]	Rowe DA et al [27]
			Linear regression analysis	ROC analysis			
MPA (3METs)	All	105	89	107	100	100 (85-111)*	100 (90-113)*
	Men	104	92	102	96		
	Women	107	91	115	107		
VPA (6METs)	All	130	ND	ND	130	ND	ND
	Men	127			125		
	Women	137			136		

ROC, receiver operating characteristic curves used to determine the step-rate cut points

ND, no data provided

*The range of step rate based on difference of leg length[26] and height[27]

Discussion:

The main purpose of this study was to use indirect calorimeter to identify a step-rate cut-point associated with activity intensity in a field environment. To our knowledge, this was the first attempt to establish a walking target for Chinese people. We identified the optimal step-rate cut point was 105step·min^{-1} for MPA and 130step·min^{-1} for VPA. Applying cut-point for MPA to calculate the walking steps and distance taken to meet PA guidelines, 30minutes of moderate-intensity activity corresponds to 3,100 steps in young men and 3,200 steps in young women, or roughly 3150 steps for both. If steps are converted to walking distance, it is about 2 km.

We tested 4 different walking speeds in this study. Three of them were significantly corresponded with PA Compendium**[20]**.When compared with EE reference from PA Compendium, the EE measured from our study was higher for three walking speeds. Previous studies showed inconsistent results when comparing measured EE with compendium reference. Some reported higher value**[21]**, others reported lower value**[22-23]**. The inconsistency might be due to difference in sample characteristics, testing methods, and test environment **[21,24,25]**. Therefore, it is not proper to perform complete result comparisons for different test condition. For the current study test setting might be a contributor to the difference. We conducted the walking test in a field setting, not on a treadmill. Our previous study found that walking-related energy expenditure in the field was different from treadmill testing**[19]**. However, the intensity of these 3 walking speeds in present study was between 4.0 and 5.5 MET, which was in the range of 3-6 MET as moderate intensity identified by PA Compendium.

Objective measurement method and larger sample size allowed this study to establish the step rate cut point related to intensity (METs) as a minimum threshold for MPA walking and VPA walking. To date, four other studies have used indirect calorimeter to validate a step-rate cut point associated with moderate or vigorous intensity walking. Simon J measured the step rate and intensity on treadmill**[14]**. Different cut-points were obtained from different statistical method, and the author concluded walking at 100 step·min^{-1}on ground level would meet the moderate-intensity walking recommendation. Tudor-Locke and his colleagues determined that 96 and 107 step·min^{-1} as the minimum threshold for moderate-intensity walking, and 125 and 136 step·min^{-1}for vigorous-intensity for young men and women**[15]**. The two other studies supported the 100 step·min^{-1}as moderate-intensity walking cadence while emphasized inter-individual variation of step rate were apparent due to anthropometric differences such as height and leg length**[26,27]**. Our finding corresponded closely with these previous studies, although our cut-point was slightly higher. The similar findings of these studies are encouraging given the differences between the sample characteristics and methodologies, which offer some evidence that will support the development of a consensus step rate recommendation for the people in different countries.

In addition, we found that there was significant difference of step rate between young men and women at the same walking speed, therefore it seems proper to have different cut point recommendation for men and women separately. The gender differences in the mean step rate may be caused by differences in height and leg-length. At the same walking speed, female's step frequency is higher than male due to shorter height and shorter lower limb. However, since the difference of step rate between men and women was less than 10 steps per min, considering the needs to establish the walking recommendation in a relatively simple way, we think that single step rate recommendation would be more effective in physical activity promotion and intervention application. Therefore, we suggest 105 step·min^{-1} and 130 step·min^{-1} cut-points to be corresponded to MPA and VPA. However, if the recommendations of individualized step rate would be developed in the future, physical differences such as height, leg length and gender should also be considered.

In order to associate our step rate cut point with PA guideline**[3]**, the minimum walking steps of 3,150 steps daily for MPA were considered based on our study results. It should be emphasized that 3,150 steps need to be taken above the basic number of daily steps**[15]**. Recent study has reported the daily walking steps goal for American people is 8000 steps, derived from accelerometer data**[10]**, but earlier study reported 10000 steps**[8]**. Since people have different physical activity patterns, it is difficult to establish consistent total number of walking steps for everyone. Moreover, there is not a comprehensive walking recommendation if only walking steps is involved but not the intensity. Therefore, it is practical and useful to provide a general suggestion that how many extra steps individual needs to take above the daily activities and how fast to walk for health promotion. Specially, Chinese young adult should walk at least 30 minutes with a minimal 105 steps/min, or 3150 steps or 2 kilometers with the same step rate daily to meet PA guidelines. They will perform vigorous-intensity activity if 130 step·min^{-1} is reached and this will provide more health benefit.

China is experiencing rapid economic growth. With the increase of private car ownership and the reduction of the intensity of work, a rapid decrease of physical activity levels of Chinese people has caused widespread concern. Data from 2007 China Physical Activity and Exercise

Survey showed that the proportion of young people aged 20-29 years to participate in regular exercise is the lowest among survey population aged 16-70 years old, with only 6.2 percent[**30**]. Walking is the most common and easy exercise. Walking above the certain speed can improve the health of people[**31**]. Therefore, a walking recommendation built on scientific evidence for Chinese young adults is a meaningful step to help them promote the physical activity levels.

One strength of the present study was large sample size and EE measurement in field settings, which provide sufficient power to identify the step rate cut- points accurately. Another strength was to provide Chinese young adults a walking recommendation in form of relative flexible assistive tool. People can achieve their own exercise goal by using different calculations, such as step rate, walking during, total walking steps, and/or walking distance. There were a number of limitations in this study. The first limitation was the small age range of young participants. It was known that gait and energy expenditure will be different between older and young individuals**[28]**. At the same walking speed, older people will have the gait of shorter step length and faster step rate**[29]**.Therefore, the cut point established might not be suitable for older population. The second limitation was the use of a constant (3.5 ml·kg^{-1}·min^{-1}) as an estimated value of resting energy expenditure, instead of a direct measurement for calculating METs. Although the use of this constant is widely accepted in the scientific literature, it is likely to overestimate resting-energy expenditure at the individual level**[23-24]**. Then, the step rate cut point developed by the estimated value of MET might be overestimated. The third of limitation was lack of cross-validation. Considering the data collected under the current controlled environment may be different from the real environment, future study should focus on establishing the validity of the current cut points through independent validation studies in real-life field walking.

Conclusion:

The step rate cut-points corresponding to activity intensity categories (in terms of MET levels) have been set up by this study. It could be useful for recommending appropriate amounts of walking exercise to meet PA guidelines for Chinese young adults. The findings from this study indicate that Chinese young adult should walk at least 30 minutes with a minimal 105 step·min^{-1}, or 3150 steps with the same step rate daily to meet PA guidelines. There were slight differences on step-rate threshold and minimal steps between women and men, so further specific step rate recommendations can be developed for different gender group.

What this study adds

1. This study shows that under the same walking speed, there was a small difference of EE due to different step rate among individuals. When the walking speed increased from 3.8km/h to 6.4 km/h, step rate and energy expenditure increased almost at the same rate.
2. This study also shows at the same walking speed, step rate was higher in women than in men, but the difference is less than 10 step•min^{-1}.
3. This study compares the data from Chinese young people's walking energy expenditure with other findings based on western participants and set up the walking recommendation for Chinese young people for the first time.

Contributors All authors were involved with the planning and designing of the study, as well as data collection. Wang Huan was responsible for the first draft of the manuscript, which was subsequently revised by all other authors.

Acknowledgements The authors thank the contribution of Dr Steven Blair and Dr Xue-mei Sui, who provided additional information for data analysis and careful modification for the text of this paper.

Competing interests None.

Project and Funding

National Key Technology Support Program（2006BAK33B03）was funded by Ministry of Science and Technology (MST) in China

REFERENCES

1. Caspersen CJ, Fulton JE. Epidemiology of walking and type 2 diabetes. *Med Sci Sports Exerc* 2008;**40**(7suppl):S519–28.
2. Eyler AA, Brownson RC, Bacak SJ, et al. The epidemiology of walking for physical activity in the United States. *Med Sci Sports Exerc* 2003;**35**:1529–36.
3. Haskell WL, Lee IM, Pate RR, et al. Physical activity and public health: updated recommendation for adults from the American College of Sports Medicine and the American Heart Association. *Med Sci Sports Exerc* 2007;**39**:1423–1434.
4. Hamer M, Chida Y. Walking and primary prevention: a meta-analysis of prospective cohort studies. *Br J Sports Med* 2008;**42**:238–43.
5. Lee IM, Buchner DM. The importance of walking to public health. *Med Sci Sports Exerc 2008*;**40**(7 suppl):S512–8.
6. Workman JM, Armstrong BW. Metabolic cost of walking: equation and model. *J Appl Physiol* 1986;61(4):1369-1374.
7. Tudor-Locke C, Ainsworth BE, Thompson RW, et al. Comparison of pedometer and accelerometer measures of free-living physical activity. *Med Sci Sports Exerc* 2002;**34**: 2045–2051.
8. Tudor-Locke C, Bassett DR. How many steps/day are enough? Preliminary pedometer indices for public health *Sports Med* 2004;34: 1–8.
9. Tudor-Locke C, Hatano Y, Pangrazi RP, et al, Revisiting "how many steps are enough?" *Med Sci Sports Exerc* 2008;40:S537–S543.
10. Tudor-Locke C, Johnson WD, Katzmarzyk PT. Accelerometer-determined steps

per day in US adults. *Med Sci Sports Exerc* 2009;**41**: 1384–1391.

11. Wilde BE, Sidman CL, Corbin CB. A 10,000-step count as a physical activity target for sedentary women *Research Quarterly for Exercise and Sport* 2001; (72)4:411-414.

12. Pearce ME, Cunningham DA, Donner AP, et al. Energy cost of treadmill and floor walking at self-selected paces. *Eur J Appl Physiol Occup Physiol*. 1983;52(1):115-9.

13. Tudor-Locke C, Rowe DA. Using Cadence to Study Free-Living Ambulatory Behaviour. *Sports Medicine* 2012;**3**: 1-17.

14. Simon J Marshall, Susan SL, Karen MW, et al. Translating Physical Activity Recommendations into a Pedometer-Based Step Goal. *Am J Prev Med* 2009;**36**:410–415.

15. Tudor-Locke C, Sisson SB, Collova T, et al. Pedometer-determined step count guidelines for classifying walking intensity in a young ostensibly healthy population. *Can J Appl Physiol* 2005;**30**: 666-676.

16. Morris JN, Hardman AE. Walking to health. *Sports Med* 1997;**23**:306–32.

17. Bertram JE, Ruina A. Multiple Walking Speed-frequency Relations are Predicted by Constrained Optimization. *J Theor Biol* 2001;209:445-453.

18. Zarrugh MY, Radcliffe CW. Predicting Metabolic Cost of Level Walking. *Europ J Appl Physiol* 1978;38: 215-223.

19. Jiang Chongmin, Qiu Shumin, Wang Huan. Comparison of treadmill and field test for energy consumption during running and walking. *Sport Science(China)*

2010;7:30-37.

20. Ainsworth BE, Haskell WL, Whitt MC, et al. Compendium of physical activities: an update of activity codes and MET intensities. *Med Sci Sports Exerc* 2000;**32**(Suppl. 9):S498–51.

21. Anjos LA, Wahrlich V, Bossan FM, et al. Energy expenditure of walking at different intensities in Brazilian college women. *Clinical Nutrition* 2008; 27:121–125.

22. Byrne NM, Hills AP, Hunter GR, et al. Metabolic equivalent: one size does not fit all. *J Appl Physiol* 2005;**99**:1112–9.

23. Gunn SM, Brooks AG, Withers RT, et al. Determining energy expenditure during some household and garden tasks. *Med Sci Sports Exerc* 2002;**34**:895–902.

24. Gunn SM, van der Ploeg GE, Withers RT, et al. Measurement and prediction of household energy expenditure in males during household and garden tasks. *Eur J Appl Physiol* 2004;**91**:61–70.

25. HALL C, A FIGUEROA, B FERNHALL, et al. Energy Expenditure of Walking and Running: Comparison with Prediction Equations. *Med Sci Sports Exerc* 2004;**36**: 2128–2134.

26. Beets MW, Agiovlasitis S, Fahs CA, et al. Adjusting step count recommendations for anthropometric variations in leg length. *J Sci Med Sport* 2010; **13**:509-12.

27. Rowe DA, Welk GJ, Heil DP, et al. Stride rate recommendations for moderate intensity walking. *Med Sci Sports Exerc* 2011; **43**:312-318.

28. Demura S, Sohee S, Yamaji S. Sex and age differences of relationships among

stepping parameters for evaluating dynamic balance in the elderly. J Physiol Anthropol.2008; 27:207-15.

29. Cavagna GA, Franzetti P. The Determinants of the Step Frequency in Walking in Humans. J Physiol 1986; 373:235-242.

30. General Administration of sports of China. The 3rd National Mass Sports Status Investigation Report. Beijing:People's Sports Publishing House of China, 2010:44-45.

31. Liu Ailing, Hu Xiaoqi, Li Yanping. Modes of Transportation by Chinese Non-agriculture Employed Population. *Chin J Prev Contr Chron Dis* 2009;2:114-116.

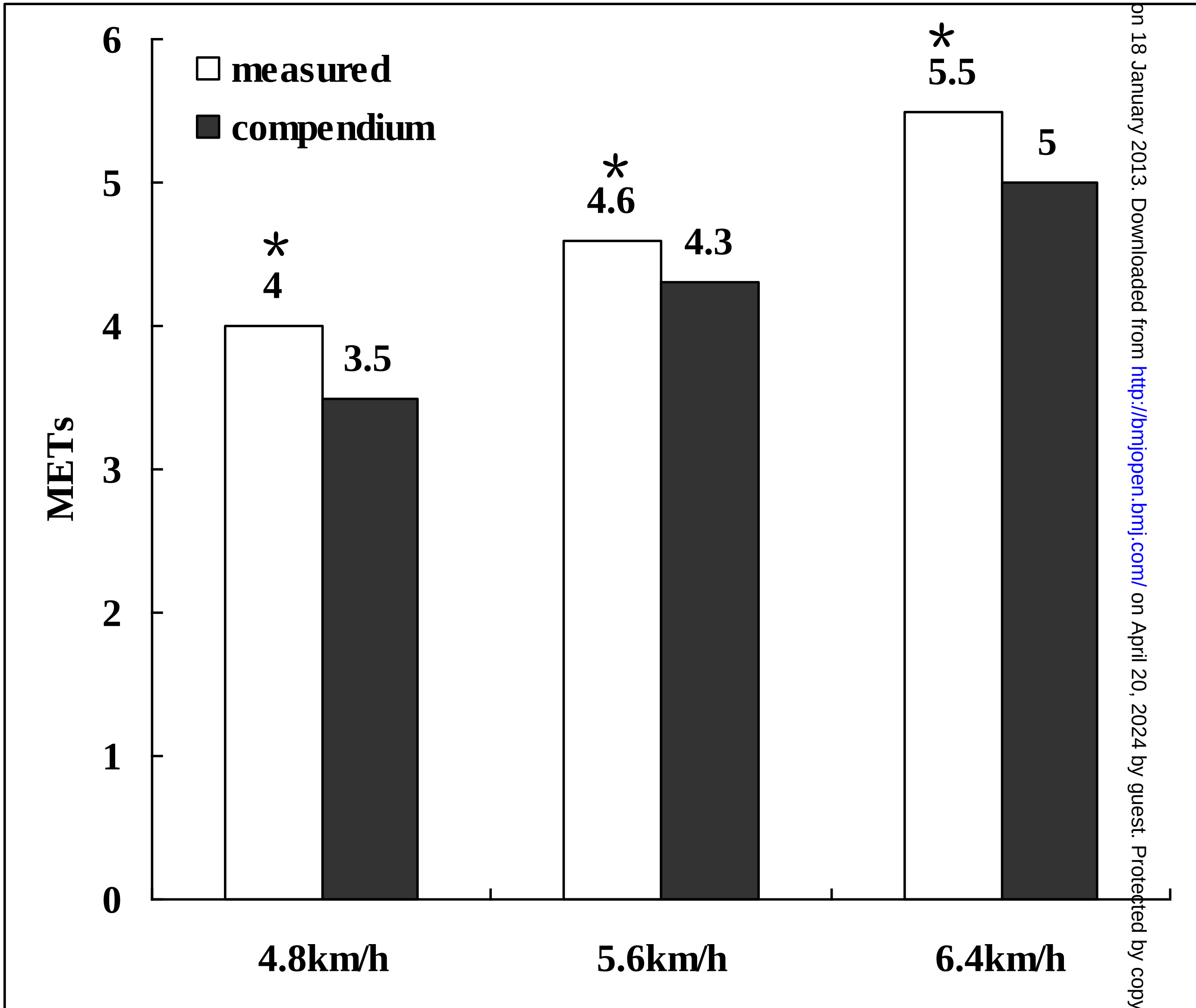
FIGURE LEGEND

White column: Measured value

Black column: PA Compendium recommendation

Title：Comparison of the measured METs value and Compendium

(* significantly different (one-sample T Test) from Compendium value)



Title: Comparison of the measured METs value and PA Compendium
(* significantly different (one-sample T Test) from Compendium value)