How does a hilly urban environment influence daily physical activity in obese individuals?

Running head: Effect of slope and weight on physical activity

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Keywords: free-living conditions, walking, behavior, model classification, physical activity prescription

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Abstract

**Background.** Increases in physical activity (PA) are promoted by walking in an outdoor environment. Along with walking speed, slope is a major determinant of exercise intensity, and energy expenditure. The hypothesis was that in free-living conditions, a hilly environment diminishes PA to a greater extent in obese (OB) when compared with control (CO) individuals. **Methods.** In order to assess PA types and patterns, 29 CO (22±2 kg/m²) and 13 OB (33±4 kg/m²) individuals wore during an entire day 2 accelerometers and 1 GPS device, around respectively their waist, ankle and shoulder. They performed their usual PA and were asked to walk an additional 60 min per day. **Results.** The duration of inactivity and activity with OB individuals tended to be, respectively, higher and lower than that of CO individuals (p=0.06). Both groups spent less time walking uphill/downhill than on the level (20%, 19%, vs. 61% of total walking duration, respectively, p<0.001). However OB individuals spent less time walking uphill/downhill per day than CO (25±15 and 38±15 min/d, respectively, p<0.001) and covered a shorter distance per day (4.1 vs 5.4 km, p<0.05). **Conclusions.** BMI and outdoor topography should also be considered when prescribing extra walking in free-living conditions.

**Keywords:** free-living conditions, walking, behavior, model classification, physical activity prescription
Background

It is widely recognized that obesity is increasing worldwide and has reached epidemic proportions. There is evidence that obesity, neighborhood environment and physical activity (PA) are interrelated \(^1\). Therefore, countering the obesity epidemic involves approaches that include changes in dietary intakes, increases in PA, as well as other behavioral modifications\(^2\). Among those factors, PA is of importance, since it is a major component of daily energy expenditure (TEE) and since it can be changed voluntarily. PA reduces the risk of coronary heart disease, hypertension, type 2 diabetes, various cancers, and premature mortality \(^1\), \(^2\). Additionally, an active lifestyle, as characterized by daily PA, is related to cardio-vascular health \(^3\). Current guidelines advocate that adults should carry out 30 to 60 min per day of moderate-intensity PA for weight and health maintenance \(^4\). However, the majority of the population does not meet current PA guidelines \(^5\) and obese individuals (OB) are known to have even lower daily PA than people of normal weight\(^6\).

Over the course of a typical day, spontaneous and structured PA are performed at different intensities and for various durations. The accurate measurement of habits or behavior of individuals towards their environment in terms of PA type, volume, duration, frequency, and intensity, is of great importance, as it may allow the identification of an insufficiently active lifestyle \(^7\) and the evaluation of the effectiveness of an intervention program designed to increase PA. Its accurate assessment is, however, difficult. Validated techniques used to quantify objectively overall daily PA energy expenditure (EE) include methods based on the utilization of stable isotopes (Doubly Labeled Water), on cardiovascular measurement (heart-rate), and on gas exchange measurements (indirect calorimetry). However, these techniques do not provide information on the PA pattern (type, volume, duration, and frequency) nor on the behavior of individuals towards their
environment. Kinematic parameters measured by accelerometers \(^8\) and GPS \(^9,14\) may in contrast provide more information about both EE and PA pattern.

Obesity may be characterized by a poor cardio-vascular health \(^15,16\), which, in turn, may influence the amount and intensity of daily PA. In an environment characterized by steep inclines, poor cardio-vascular health/performance may indeed influence the types of PA performed by obese individuals, and hence the PA EE.

In this context, we hypothesized that, in an environment characterized by inclines, OB individuals are tempted to avoid steep positive slopes and to decrease walking speed during spontaneous outdoor PA, as well as during prescribed structured bouts of exercise. In order to investigate the PA of OB and their predicted energy expenditure (EE), we determined the type, intensity and duration of daily PA performed indoors and outdoors by means of a model that combines data from a GPS device and 2 accelerometers.

**Methods**

**Participants.** Forty-two normal weight (n=28, 12 female and 16 male) and obese (n=14, 7 female and 7 male) subjects participated in the study. All participants were recruited by advertising from the City of Lausanne (Switzerland). One of the characteristics of this city is its hilly environment and steep streets. Their height was measured using a stadiometer, and their body weight measured to the nearest 0.1 kg (SECA 708, Hamburg Germany) with participants wearing only underwear. Body fat was estimated using 4 standard skinfold measurements and the equation of Durnin and Womersley \(^17\). Normal weight control subjects had a BMI ranging from 18.5 to 25 kg/m\(^2\), whereas obese subjects had a BMI ranging from 30 to 35 kg/m\(^2\). The physical characteristics of participants are presented in Table 1. Within groups, males and females had no difference in BMI (\(x\)-squared = 0.012, \(p = 0.9\)). Inclusion criteria were: in general good health, non-smoking, able to engage in normal walking
activities, not involved in regular structured PA, and without metabolic or orthopedic disorders. All subjects performed less than 2h/week of sporting activities as assessed by a general PA questionnaire. After being fully informed of the procedures of the study protocol, participants gave written informed consent. This study was approved by the Ethics Committee of the Faculty of Biology and Medicine of the University of Lausanne, Switzerland.

**Experimental Protocol.** Each subject performed 2 test days. Each test proceeded as follows: subjects reported in the morning to the laboratory at 8:30 AM. Anthropometric measurements were first performed. Then, the subjects were equipped with 2 accelerometers and 1 GPS, worn on the waist, ankle and shoulder, respectively, and were instructed in how to use the devices. Immediately after, an individual calibration trial was performed outdoor (in the vicinity of our department) on the level and on different slope gradients to determine their spontaneous walking characteristics (i.e. speed and stride frequency (SF) at slow, preferred and fast walking speed). The calibration performed outdoors consisted in walking 200m horizontally at the subject’s preferred speed, 200m at their fastest walking speed, followed by 300m uphill (8% slope) at a slow speed, and 300m downhill (-8% slope) at the fastest speed they could reach without running. This procedure was used to determine the range of stride frequency and the speed of each subject. This was subsequently used by the model to accurately assess PA and EE. The duration of the calibration procedure ranged from 10 to 13 min. Then, the subjects were instructed to perform their usual daily activities, to wear the 3 sensors until bedtime and to take them off for the night. Finally, the subjects were asked to add a 60 min walking block to their usual activities. The following day, the subjects brought the sensors back to the laboratory. Data were downloaded from the 3 sensors and stored in a computer to be subsequently processed by the model for PA and EE assessment.
**Instruments.** The determination of PA type, duration and intensity, as well as the assessment of EE, relied on data obtained by three sensors: 1) the uniaxial accelerometer Lifecorder Kenz EX (LC; Suzuken Co. Ltd., Nagoya, Japan), worn on the waist, 2) the dual-axis accelerometer Step Watch 3 Activity Monitor (SAM; Cyma Corporation, Mountlake Terrace, WA, USA) worn on the ankle, and 3) a Global Positioning System (GPS) (FRWD Technologies, Finland) worn on the shoulder. The Lifecorder detects vertical accelerations of the body and classifies them into 11 levels (0, 0.5, and 1–9, walking corresponding to an intensity level between 3 and 7). The Step Watch 3 Activity Monitor combines acceleration, position and time data to count the number of strides. The recording frequency was set at 0.17 Hz and synchronized with the internal clock. Instantaneous speed and altitude were recorded at 0.17 Hz by the GPS. GPS tracking has been used extensively recently for determining the speed profile during outdoor exercise \(^9\), as well for the measurement of gait parameters in free-living conditions \(^{10-14,19}\).

**PA recognition and EE estimation.** A hierarchical model was developed for PA recognition (Nguyen et al., unpublished data). In this model, the PA classification process is defined by a sequence of logical conditions to be tested against the characteristics of PA. In brief, data was processed according to the following procedures. First, data was averaged over 1-minute intervals. Second, the model combined the raw data sets measured by the 3 independent sensors for PA classification on a minute-by-minute basis (Fig.1). In this study, the PA were classified into 8 categories: 1) walking, 2) burst displacement, 3) use of a motorized vehicle, 4) running, 5) sitting/standing (swing/seesaw), 6) indoor sedentary activities, 7) sitting/lying still, and 8) cycling. Resting metabolic rate (RMR) was predicted by the equation of Mifflin \(^{20}\) based on body weight, age, sex and height. EE during the different PA categories (PAEE) was predicted using previously published equations and a compendium of PA \(^{20-25}\). Data from our laboratory showed that this method was valid and
reliable for an accurate assessment of PA pattern and total daily EE (TEE, equ.1) (Nguyen et al, unpublished data). Total daily energy expenditure was calculated as the sum of RMR, PAEE and the thermic effect of food, assumed to represent 10% of RMR$^{26}$.

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\text{TEE}=\text{RMR}+\text{PAEE}+0.1\cdot\text{RMR}
\]

\[
\text{equ.1}
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**Statistical analysis.** A linear regression model was used to analyze the relationship between variables and Pearson’s correlation coefficient was computed to study the degree of association between variables. The effects of BMI on the gait parameters and their adaptation to slopes were tested using a two-way ANOVA. To investigate differences between groups, unpaired t-tests were used. Matlab (MathWorks; Natick, MA) was used for statistical analysis. Results are presented as means with SD and p-value was set at $\leq 0.05$. Results of the first and second trials were averaged, since no significant difference was observed between the first and the second day test with regard to PA and predicted EE.

**Results**

**Total PA, PA types and pattern.** A typical case of a daily PA pattern is shown in figure 1. Overall, CO and OB performed 847±52 min. and 854±90 minutes of PA, respectively. The duration of each PA category was comparable between CO and OB (p=0.07, Fig. 2). However, inactivity tended to be higher in OB vs. CO (p=0.06), with inactivity being defined as lying/sitting still and use of a motorized vehicle. We found that the OB group had a longer period of inactivity and a shorter period of physical activity. The periods of inactivity represented 60±8% and 55±9% of day time in OB and CO, respectively.

**Walking.** Total walking duration was 94.3±21.4 min and 87.4±27.1 min (p=NS) in CO and OB, respectively (Fig. 2). In both groups, time spent walking on a horizontal plane was significantly greater (p<0.001) than the time spent walking on negative or positive
inclines (Fig. 3). In addition, the OB group spent significantly less time walking on slopes than the CO group (p≤0.05).

**Effect of slope on walking speed and stride frequency.** The SF and walking speed were assessed during walking on slopes ranging from -10% to 10% (Fig. 4). Overall, a significant impact of slope and BMI was observed on the walking speed (p<0.05). Walking speed decreased as slope increased (figure 4 A). Walking speed was significantly lower in OB for slopes ranging from -10% to +5% (p<0.01). Walking speed was negatively related to body weight at slopes from -10% to +5% (r=-0.45 to -0.3, p<0.01 to p<0.05, data not shown). On steeper positive slope (10%), no significant relationship was found between body weight and walking speed. Similarly, there was a significant interaction between BMI and slope on SF (p<0.05), the OB group having a lower SF than the CO group (Fig. 4).

**The total number of steps per day** was 18’500 ± 3’111 steps for the CO group, noticeably higher than in the OB group (16’253 ± 4’331 p<0.05). Steps taken during the 60 minutes walking prescription were included in this average.

**Walking distance covered per day.** Over the day, CO subjects covered 5.2±1.6 km (range 2.49-8.7 km) daily, which was significantly higher than in the OB group (3.8±2.1 km, range 0.9-9.6 km, p<0.01). This only includes continuous walking, i.e. walking bouts greater than 1min. Total distance was negatively associated with body weight (r=-0.4, p<0.01).

**Proportion of steps performed in different PA categories.** The proportion of total steps allocated to different PA in the CO and OB groups respectively were, as follows: for walking 60.8±13% and 55.5±13%, for indoor PA 22.8±6% and 26.9±6%, for burst walking 14±10% and 16.2±12%, for running 1.1±4% and 0.2±0.5%, and for cycling 1.3±2% and 1.3±3%. No significant difference was found between groups. However, significant differences between activity categories within groups were found (p<0.001), except between running and cycling.
Total daily EE. TEE was significantly higher in OB female subjects than in CO female subjects (2'786±233 kcal/d and 2'208±363 kcal/d respectively, p<0.001) (Fig. 5). In male subjects, TEE in OB was higher than in CO, with the difference near the statistically significant level (p=0.09). Positive correlation was observed between TEE and body weight in women (r=0.88, p<0.01), as well as in men (r=0.79, p<0.01).

Discussion and Conclusion

A sufficient level of PA is fundamental in the prevention of certain chronic diseases 1, 2. In order to refine and to individualize intervention programs for improving health and weight management, PA should be assessed objectively and reliably in the natural environment of the subjects. In this study subjects’ PA behaviour in a hilly city during a whole day was determined. Our data clearly indicates that, when prescribing PA to different populations, the natural characteristics of the environment, especially slopes and inclines, should be taken into account, as it influences the performed workload and hence energy expenditure.

Effect of slope on walking in free-living conditions. First, our results indicate that both CO and OB groups walk spontaneously more on the level rather than on a steeper slope. Also, our data indicates that the OB group spent more time walking on horizontal pathways and less on inclines than did the CO group. Probably, the greater EE and relative effort in obese individuals for achieving certain PA due to their excess weight 15, 16 lead the obese subjects a) to have a less active lifestyle, b) to walk at lower speed, and c) to avoid steep slopes in a hilly urban environment, since walking on the level would be more comfortable. In concordance with Prentice et al. 27 and Ekelund et al. 15, it could be observed that the OB group has a higher TEE (Fig. 5), due to their higher RMR, and not their higher level of PA. This is evident when the relative PA is calculated as physical activity level
(PAL=TEE/RMR): 1.56±0.8 vs. 1.68±0.2 for OB and CO, respectively. Since the intensity of exercise can be self-tuned, and terrain pathways and trajectories can be self selected (for example, positive slopes can be avoided while walking), it seems necessary in the future to evaluate the PA level, as well as the type of different daily exercises, in order to adjust activity prescriptions in intervention programs. For example, 30 min of walking in a horizontal environment would, in terms of EE, correspond to about 20 min of walking at a 5% gradients \(^ {28}\) at the same speed.

**Effect of slope and BMI on gait parameters.** In the present study, the CO group, as compared with the OB group, had a lower walking speed on any slope, which is likely due to a lower SF (p=0.07). In agreement with these findings, a recent study \(^ {29}\) has shown lower preferred speed and SF in obese subjects under lab conditions, i.e. while walking on the treadmill. Also, we observed that gait parameters while walking were influenced by the terrain slope. Our results are consistent with Lai et al. \(^ {30}\) and Minetti et al. \(^ {28}\), who found that walking speed and SF decreased as the slope increased.

**Physical activity and inactivity in OB vs. CO.** Many studies have demonstrated that a too high placidity has deleterious effects on a person’s health \(^ {7,31-33}\). The results of the present study indicate that the CO group was generally more active than the OB group. In concordance with Lindström et al \(^ {34}\), the CO group performed a greater number of steps, and covered a greater distance. Opportunities for sedentary behavior are ubiquitous, and what people do in their leisure time (spontaneous PA) is as important as a structured program PA (i.e. sport) for weight management \(^ {35}\). In the present study, inactivity periods in the CO group were found to be shorter than those in the OB group, leading to a higher than expected non-exercise activity thermogenesis (NEAT) in the CO group, i.e. a higher total EE due to spontaneous activity. Promoting NEAT through decreasing inactivity periods (e.g. reducing
TV watching) and increasing volitional PA contributes to preventing overweight and obesity\textsuperscript{36}.

**Important considerations for PA prescription.** Numerous studies recommend a certain number of steps per day \textsuperscript{37}, and a daily brisk walking of 30-60 minutes per day in order to meet the daily PA requirements for health maintenance \textsuperscript{38}. However, the recommended number of steps and brisk walking duration do not take into account the different activity types or intensities (such as walking speed). These do not produce the same effects on health-related factors. Therefore, instead of a 10’000 steps per day prescription \textsuperscript{37}, Marshall et al. \textsuperscript{39} suggested prescriptions of either daily 3’000 steps during 30 minutes for 5 days a week, or three daily bouts of 1’000 steps during 10 minutes for 5 days a week. Thus, measurement of the number of steps specific to each PA type would valuably complement the recommendations for health maintenance. In the present study, we found that about 60\% of total steps recorded were attributed to continuous walking (including the 60min walking), and 15\% to burst walking. The remaining steps were due to other non-walking activities. A refined assessment of qualitative aspects of the recommended number of steps performed in each PA category, at each slope, at each speed would be desirable.

**Future research and research limitation.** Our study was based on 2 day measurements of PA with an extra 60 min walking prescription, in order to ensure a baseline activity. Indeed longer periods of assessment are generally considered to better reflect the daily PA pattern of individuals and the response to PA prescription \textsuperscript{40, 41}. However, this preliminary report indicates that qualitative data in the assessment of individual PA behaviors may be of interest in the future in order to individually refine walking prescription based not only upon step counts, but also considering the general pattern of PA, PA types, and the subjects’ anthropometrical characteristics. Seasonal effects on PA are yet another aspect that should be considered \textsuperscript{42, 43}. The next step, in order to track habitual PA and to generalize the
behavior of obese individuals in their real-life conditions (i.e. without exercise prescription), should consist in measuring the PA of individuals over longer periods (e.g. a whole week up to a year), taking into account particular periods influencing the PA behavior such as weekends^{40,41}.

**Conclusion.** For the purpose of increasing the intensity of PA, walking in hilly or mountainous environment may constitute a benefit for individuals. This can be achieved at a self-tailored speed in function of the slope and body weight. Since some weight bearing PA, such as running, are not recommended^{44} for obese individuals, walking uphill, even slowly may constitute an alternative. Quantifying the behavior of individuals, in particular how they tackle hilly environments or avoid slopes in their every day displacements, would allow more adapted PA prescription.

In conclusion, outdoor topography (presence or absence of natural slopes) as well as BMI should be also considered when prescribing extra walking in free-living conditions, and should be tailored to the physiological cardio-respiratory characteristics of the patients.

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References


Figure 1 - Daily pattern of PA measured by 3 sensors in a normal weight subject (F, 22y, 168cm, 57kg, and 25% body fat). It can be seen that the different categories of PA are well identified: for example the "walking" category is clearly recognizable by its typical accelerometric intensity (3 to 6), its stride frequency (50 to 60 strides/min), as well as its corresponding speed (4 to 6 km/h). In addition, "use of a vehicle" category is evidenced in the figure 1 by a minimal (or no) intensity of exercise, minimal (or no) stride frequency combined with the high moving speed (approx. 100km/h). (Nguyen et al., unpublished data)
Figure 2 - Daily duration of 8 habitual PA categories in the OB and CO groups. No statistical significant difference was found among groups.
Figure 3 - Duration of walking (expressed in percentage of total daily walking duration) at positive, negative, and horizontal slopes. The duration spent on negative and positive slopes was significantly reduced as compared to walking horizontally for both CO and OB groups. (*p<0.001). OB groups spent more time walking horizontal than the CO group (**p<0.05).
Figure 4 - Speed and stride frequency of walking at different slopes (-10% to 10%) in OB and CO groups. Statistically significant differences were found among and between groups for walking speed, and among CO group for step frequency. *p<0.05, **p<0.01, ***p<0.001.
Figure 5 - Daily energy expenditure (EE) in the OB and CO groups categorized by gender. Only in women was the difference among group significant (p<0.01).
**Table 1.** Anthropometric characteristics of the 2 groups of subjects. BMI: body mass index. *p<0.01 among groups.

<table>
<thead>
<tr>
<th>Physical characteristics</th>
<th>Control subjects (CO) (12F/16M)</th>
<th>Obese (OB) (7F/7M)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (y)</td>
<td>25 (4)</td>
<td>28 (5)</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>65 (9)</td>
<td>101 (14)*</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>173 (9)</td>
<td>174 (8)</td>
</tr>
<tr>
<td>BMI (kg · m⁻²)</td>
<td>22 (2)</td>
<td>33 (4)*</td>
</tr>
<tr>
<td>Body Fat (%)</td>
<td>19 (6)</td>
<td>37 (7)*</td>
</tr>
</tbody>
</table>