4. 身体活動記録

身体活動記録は，設定された期間中の活動を前向きに記述していくため，活動の種類，時間，頻度等の情報が正確に得られる方法である．身体活動記録は，実際の活動名をそのまま記入もしくはコード化したものを記入するため，活動種類などの質的な検討も行なえる．通常，活動時間やそれぞれの活動に対して活動強度値を当てはめる作業を行なうことでエネルギー消費量などの量的な検討も行なえ，得られる情報量が多い利点がある．しかし，対象者に対して活動を記入するための労力を強いることから調査協力が得られにくい，調査のコンプライアンスが低いなどの欠点がある．

5. 身体活動日記（log）

身体活動日記は，活動の種類，時間等を 1 日単位のチェックリスト形式で記入していく方法である．研究の目的に応じて作成し使用する場合や特定の活動に焦点をあてて，その活動の実施を確認するために使用されることが多い．既述の身体活動記録と類似した側面もあるが，記入量が少なく抑えられ，対象者の負担を軽減できる方法である．一方で，情報量の減少や 1 日単位でまとめて活動内容を記入（チェック）することから思い出しのバイアスが入るなどの欠点も多い．

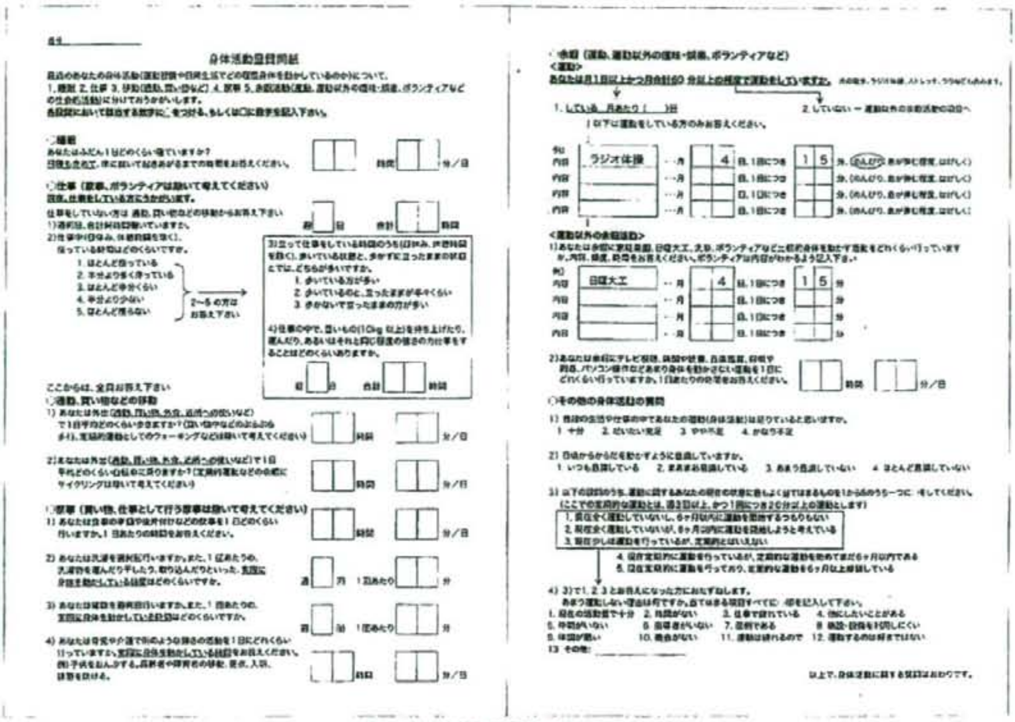
6. 質問紙法

多人数を対象にした疫学研究や健診，生活指導などで評価する場合には，調査対象集団の特徴を考慮し，適用する調査方法が実施可能性の高い方法であるかどうか検討しておくことも必要である．このような条件下では，比較的安価で，工夫次第ではさまざまな活動を評価しうる質問紙法が選択肢となる．質問紙を選択する際には，調査対象とする期間（平均的な活動量を把握したいのか，過去 1 週間や 1 ヶ月の活動量を把握したいのか），活動内容の構成（睡眠，仕事，家事，余暇活動などの種類に着目した分類であるのか，あるいは強度に着目した分類なのか），評価の単位（エネルギー消費量なのか，質問紙固有の単位であるのか）など，着目すべき観点がいくつかある．また，信頼性や妥当性が検討されているかどうかも重要な情報といえる．

現在，運動疫学研究でよく用いられている身体活動量の評価法としては，7day-recall，PAI（Physical Activity Index），IPAQ（International Physical Activity Questionnaire）などの質問紙を用いた方法がある．これらの評価法はいずれも米国で開発されたものである．なお，日本人を対象とした質問紙による身体活動量評価法としては，Japan Arteriosclerosis Longitudinal Study において JALS-PAQ（Physical Activity Questionnaire，図1-7）が開発されている6)．参考までに，質問紙を開発するにあたってとくにこだわったポイントを列挙した．

IPAQ
世界各国の身体活動量の現状を把握し，国際比較するために，WHO のワーキンググループ（参加 12 か国）により開発された調査票．

①比較的短時間で容易に調査可能（面接チェックが望ましいが，自記式でも可）
②定量評価できる妥当性の比較的高い質問紙



図Ⅰ-7　身体活動質問紙（JALSPAQ）[6]

③ さまざまな活動（睡眠，仕事，移動，家事，運動，その他の余暇活動）の状況を評価できる

④ 運動強度の評価ができる（中等度の身体活動に時間の評価が求められている）

⑤ 不活動の時間（Sedentary Activity）の評価が可能

⑥ 運動の種目，頻度，1回の時間，強さなどの詳しい情報が得られる

⑦ 身体活動量確保への意欲，運動習慣の変容ステージ，阻害要因等，保健指導に有用と考えられる質問を含む

⑧ 身体活動量の自己評価を含む

※ このJALSPAQの妥当性に関しては，24時間身体活動記録と加速度計の2つの方法による消費エネルギー量を比較基準として検討し，欧米の著名な質問紙に劣らない結果を認めた．

(1) 調査期間

質問紙には，調査対象となる期間を明示せずに，対象者の習慣的な活動量を問うものと過去の一定期間の活動を思い出し回答する質問紙とがある．後者の質問紙の思い出しの期間は3日間，1週間，1ヶ月，12ヶ月，若年期まで遡るものなどさまざまである．過去1週間の活動を思い出す形式では，Stanford Five City Project[7]，Coronary Artery Risk Development in Young Adults（CARDIA）Study[8] における7day recall質問紙が代表例である．若年期までに遡り調査する質問紙とし

ては，乳がんの研究等で使用される Historical 質問紙9)，Life Time Total 質問紙10)，骨密度と身体活動の関連を検討する目的で開発された Bone Loading History 質問紙がある11)．後者を用いた研究では，骨密度に対する身体活動の影響は，若年期の身体活動，特に重力方向の機械的刺激が高骨密度の獲得に対し有用であるとされている．この質問紙は，身体活動における物理的刺激の側面に着目し，主要なスポーツに対して骨密度負荷スコアを評価している．思い出しの期間が長くなるほど，思い出しに記憶の問題が生じ，妥当性の検証も難しくなるなど問題がある．

(2) 活動種類

従来の質問紙では，職業性の活動や余暇活動（スポーツ）中心のものが多かった．近年では，性別や年齢を意識し，家事，運動以外の余暇活動，社会活動（ボランティアなど）などを調査対象に含む質問紙が開発されている12,13)．これらの質問紙を用いた研究からは，女性や高齢者において日常生活活動を含めて身体活動を包括的に評価することの重要性が明らかにされている．

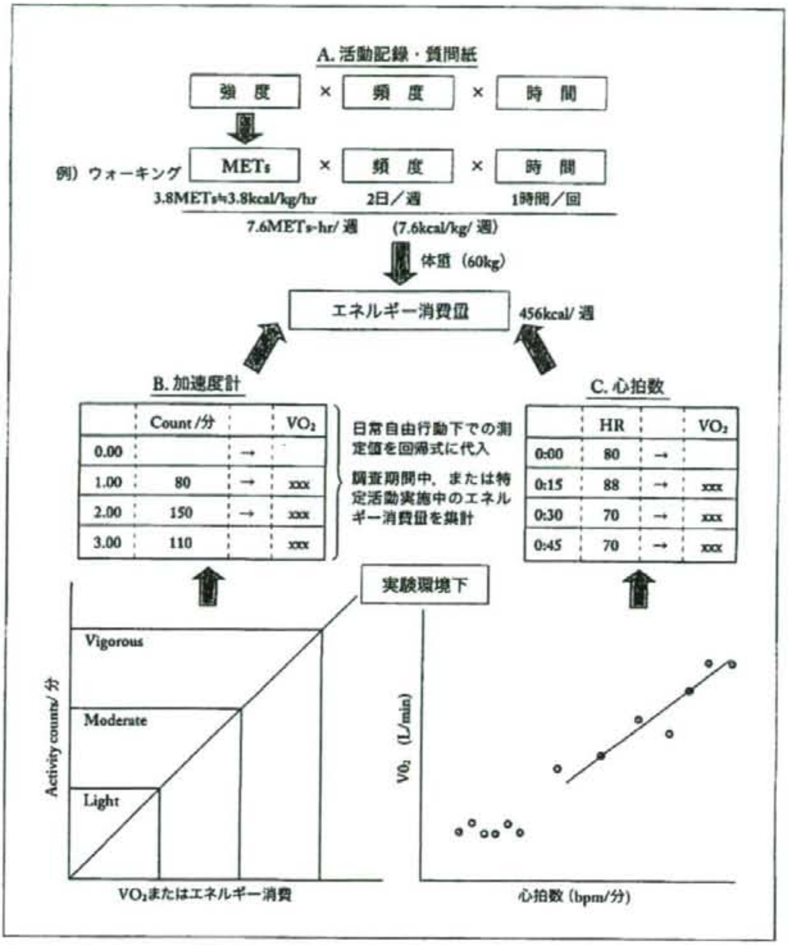
(3) 活動量の定量化

質問紙による調査では，身体活動量をエネルギー消費量として評価する方法もしくは独自のスコアを算出し評価する方法のいずれかをとる場合が多く，「活動の時間（活動 1 回あたりに要する時間）」，「週または月あたりの頻度」，「活動の強度」を調査しこれらを乗ずることにより消費エネルギー量を算出する．エネルギー消費量を計算する上で使用される単位としては，一般的には，座位の状態での酸素摂取量（安静時代謝量）を基準にその倍数で表現される METs（Metabolic equivalents）が用いられることが多い．安静時の酸素摂取量は 3.5 mlO_2/kg/ 分とされており，酸素 1 リットルの消費が 5.0 kcal のエネルギーに相当することから，安静時代謝量（1MET）は，約 1.0 kcal/kg/ 時（1.05 kcal/kg/ 時）と表現できる．たとえば，週 2 回，1 回あたり 1 時間のウォーキング（3.8 METs）を行なった場合，週あたりの総時間は 2 時間 / 週，消費エネルギー量は 7.6 METs-hr/ 週（7.6 kcal/kg/ 週）となる（図 I-8）．この対象者の体重が 60 kg であるとすれば，ウォーキングによる消費エネルギーは，456 kcal/ 週と計算される．この計算において，ウォーキングを 3.8 METs の強度の活動として計算しているが，これらの値は，さまざまな活動についての強度値が示されたリスト（Compendium of Physical Activities）に従い設定している14)．身体活動研究ではこのリストの強度値をもとにエネルギー消費量の算出を行なうことが多い．

Compendium of Physical Activities
疫学研究で質問紙等を用い，身体活動評価を行う際に，活動強度を標準化できるように開発された．1993 年に初版，2000 年に改訂版が出され，多くの研究で使用されている．

(4) 妥当性

質問紙により推定された身体活動量は，既述のように対象者に一定期間の活動を思い出させ，身体活動を構成する要素（種類，強度，頻度，時間）別に回答を導き，算出することから，途中のさまざまな過程で誤差を含みやすい．このため，質問紙法により推定した値が真値にどの程度近いか（妥当性）を確認しておく必要がある．一般には，妥当性は，質問紙よりも精度の高い指標を真値に代わる比較基



	Count /分		VO₂
0.00		→	
1.00	80	→	xxx
2.00	150	→	xxx
3.00	110		xxx

	HR		VO₂
0:00	80	→	
0:15	88	→	xxx
0:30	70	→	xxx
0:45	70	→	xxx

図I-8　異なる調査方法で得られた値をエネルギー消費量に変換する方法

A: 活動記録・質問紙によるエネルギー消費量算出方法．回答された活動の種類に該当する強度（METs 値）に時間と頻度をかけあわせて算出する．

B: 加速度計によるエネルギー消費量算出方法．日常の自由行動下で測定された値を加速度計の1分あたりのカウント数と酸素摂取量の関係式（さまざまな関係式が報告されている）に代入し，一定時間のエネルギー消費量を算出する．

C: 心拍数によるエネルギー消費量算出方法．予め実験室下で作成した心拍数と酸素摂取量の関係式に，日常の自由行動下で測定された値を代入し，一定時間のエネルギー消費量を算出する．Flex HR 法の場合は，安静相と運動相にわけて関係式を作成する必要がある．

準にして，平均値の差や相関係数などで評価されることが多い．相関係数をもとに妥当性を評価する際には，解釈を行なう上でいくつか注意すべき点がある．通常，相関係数が高いということは，身体活動量の少ない人と多い人をうまく分類する（順序づけ）能力が高いことを示している．仮に，順序の妥当性が高くても，真値とはかけ離れ平均値の推定精度が低い場合もあるので注意が必要である．また，真値の基準をどのような指標としているかも注意が必要である．2つの調査方法が類似した方法（質問紙と類似の形式の日記など）であると，両者に共通した誤差が含まれ，見かけ上相関が高くなることもありうる．

7. カロリメトリー

ルームカロリメーターは，現状で最も精度の高い方法ではあるが，閉鎖され監視下の環境にあることから活動が制限され，日常の生活とは異なる行動をとる可能性が高く，対象者の日常の活動レベルを評価する方法としては限界がある．これに対し，フィールドでも実施可能な方法として，ダグラスバッグ法や携帯型呼

気ガス分析器を用いた方法があげられる．ダグラスバッグ法は，測定対象者にマスクを装着させ，身体活動中の呼気をバッグ内に収集し，呼気中の酸素消費量（換気量）と二酸化炭素産生量を測定しエネルギー消費量を算出する方法である．携帯型呼気ガス分析器による方法は，マスク，測定器，バッテリーと測定データを受信するレシーバーなどから構成される．ダグラスバッグ法，携帯型呼気ガス分析器による方法はともに，少人数を対象とする研究で用いられる．スポーツ選手の体力評価や日常活動の活動強度の評価，質問紙や加速度計などの他の身体活動評価方法の妥当性研究などで使用されることが多い．

8. 心拍数法

心拍数法によるエネルギー消費量推定の原理は，運動強度の増大にともない，酸素摂取量（以下，VO_2）と心拍数との間に直線関係が成り立つことを前提としている．しかし，心拍数と酸素摂取量の間に直線関係が成り立つのは運動強度が 40% $\dot{V}O_2max$ 以上，心拍数で 110 〜 120 拍 / 分から 170 拍／分程度までと考えられている．また，心拍数は姿勢，精神的状態，食事摂取，カフェインなどの刺激物，薬物，環境温度などの影響を受けることから，低強度の身体活動についてはこれらの影響を大きく受けることも指摘されている．そこで，これらの問題を回避するための方法として，心拍数と酸素摂取量が直線関係にある部分（運動相）とそうでない部分（安静相）とを分ける分岐点を設け，その前後で異なる回帰式を作成し，別途測定した日常活動下の心拍数を代入し，エネルギー消費量を推定する FlexHR 法が提案されている 15)．心拍数法で個人のエネルギー消費量を推定する場合には，運動負荷試験を実施し，個別に心拍数と酸素摂取量の回帰式を作成しなくてはならない．これに加え，日常生活下での心拍数の連続測定も必要であり，これらの作業には多くの手間と時間を要する．心拍数と酸素摂取量の直線関係は定常状態が条件であるが，実際の日常生活活動は連続的な状況は少なく定常状態となることは少ないといえ，このことは心拍数法で消費エネルギー量を推定する際の問題点としてあげられる．

9. 二重標識水法

二重標識水法によるエネルギー消費量測定法は，酸素の安定同位体である ^{18}O および水素の安定同位体である ^{2}H（重水素）で二重にラベルした水を用いる．この水を対象者に経口投与すると，数時間で体内水分プールにおいて水素と酸素の同位体比（$^{1}H/^{2}H$ および $^{18}O/^{16}O$）は平衡状態になる．いったん平衡状態に達した体内の同位体比は，^{2}H と ^{18}O が水分および二酸化炭素（以下，CO_2）として体外に排泄されることによって経時的に減少する．この減少する体内での同位体比は，排泄される尿中の酸素および水素の同位体比を経時的に測定することによって得られる．^{2}H は水分としてのみ排泄されるのに対し，^{18}O は水分および CO_2 として排泄されるため，初期値からの減少速度は ^{2}H に比べ，^{18}O で速い．この減衰率の違いを利用してエネルギー消費量を求める．

1.3.3 異なる方法で調査された指標の比較

異なる調査方法で得られた値を研究等で使用するためには統一した単位で変換し評価を行なう必要性が生じてくる．図I-7に，質問紙法や身体活動記録，加速度計，心拍法の算出法およびエネルギー消費量への変換法を示した．質問紙法や身体活動記録では活動の種類や時間，頻度の情報が得られるため，これらの変数を乗じることで，消費エネルギー量がMETs-hr/週もしくはkcal/kg/時の単位で表現可能となる．加速度計による方法では，たとえばActigraph（CSA）などでは，1分あたりのカウント数と酸素摂取量の回帰式を作成し，酸素摂取量からMETs-hrやkcalの単位に変換する方法がとられる．この回帰式については，機種や対象によってさまざまな推定式が開発され報告されている[16]．これに対し，Flex HR法に代表される心拍数法では，個人ごとの推定式の作成が基本であり，図I-7に示したような酸素摂取量と心拍数の関係式を各々の対象用に作成し消費エネルギー量に変換される．

1.3.4 おわりに

さまざまな身体活動調査方法を紹介したが，どの方法にも利点と欠点が存在し，身体活動量評価として万能な方法が存在しないのは事実である（表I-5）．仮に，妥当な方法を選択できたとしても，身体活動は毎日少しずつ異なっており，曜日による違いや季節による違いなどがあるということも考慮し評価を行なう必要がある．

調査に用いる身体活動調査方法を決める際に，妥当性や信頼性が高いなど，精度の側面に目が行きがちであるが，ここで強調したいことは，なぜ身体活動量を評価しなくてはならないかという研究や調査の当初の目的を見失わないで欲しいということである．

（原田　亜紀子・内藤　義彦）

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表 I-5　身体活動評価方法の利点と欠点

方法	利点	欠点
行動観察法	・量的，質的な情報が詳細に得られる ・目的に応じて，必要とする情報を比較的自由に変えられる ・PC や PDA などを活用することでデータ収集やコーディング等に幅が持たせられる	・観察者は調査方法に習熟しておく必要がある（トレーニングが必要） ・時間と手間がかかるので，対象数は限定される ・観察者の存在が，被調査者の活動に影響する可能性がある
加速度計	・実験室下でもフィールド下でも用いることが可能 ・強度，頻度，持続時間の客観的な情報が得られる ・対象者の負担が少ない ・調査後，データ入力等の必要がない ・設定をすることによって，短い時間間隔で強度情報が得られる ・機種，メモリー機能に依存するが，比較的長期間のデータ収集が可能	・機器が高価なため，大規模集団に対する調査は難しい ・調査開始時に機器の設定が必要となる ・上肢のみの活動，傾斜での歩行などは捕捉できない ・水中での活動（水泳，入浴等）は評価できない ・機器のエラー等で故障した場合のデータ損失が避けられない
歩数計	・費用は比較的安価 ・管理が容易である（機器の設定等不要） ・指標が「歩く」という一般的な活動なため理解しやすい	・装着し表示を確認することで活動が変わる可能性がある ・ジョギング等では歩数が不正確である ・歩数という活動しか評価できない
質問紙	・量的，質的両方の情報が得られる ・目的に応じて，必要とする情報を比較的自由に変えられる ・費用は比較的安価 ・大規模集団に対して実施することが可能である ・活動種類から強度をあてはめるなどして，エネルギー消費量の推定が可能である	・対象に応じ，適切な質問紙を選択しなければ内容妥当性の問題がある ・思い出しによるバイアスは生じやすい
カロリメトリー	・精度の高い方法である	(ルームカロリメーター) ・室内での活動に限られ，自由行動下の活動評価が行えない ・設備が大掛かりである (ダグラスバック・携帯型呼気ガス分析器) ・対象者にマスクや分析器を装着する必要があり，負担がかかる ・呼気ガス分析器のキャリブレーション等の精度管理が必要である
心拍数	・一定の強度以上であれば，エネルギー消費量との相関がよい ・実験室下でもフィールドでも用いることが可能である ・活動の強度，頻度，時間が評価可能である ・調査後，データ入力の必要がない	・心拍数は姿勢，精神的状態，食事摂取，カフェインなどの刺激物，薬物，環境温度の影響をうける ・HR の測定時間が長くなると対象に負担となる ・有酸素運動のみの評価，筋力トレーニングなど静的運動の評価が難しい ・低強度の活動ではエネルギー消費量推定が不正確である
二重標識水法	・精度の高い測定方法の一つ ・活動に影響を与えず身体活動が評価可能	・費用が高額なため，少人数での調査に限られる． ・生体試料（尿，唾液等）の供出が必要である ・活動の種類が評価できない

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Twenty-four–hour analysis of elevated energy expenditure after physical activity in a metabolic chamber: models of daily total energy expenditure[1–3]

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ABSTRACT

Background: The Institute of Medicine proposed that 15% of energy expenditure (EE) as excess post-exercise oxygen consumption should be added to additional physical activity energy expenditure (ΔPAEE) to estimate total EE. However, the magnitude of elevated post–physical activity energy expenditure (EPEE) under normal daily living conditions has not been examined.

Objective: We examined the effects of EPEE on 24-h EE by modeling standard living conditions in a metabolic chamber.

Design: Eleven Japanese men completed three 24-h metabolic chamber measurements: a control day (C-day), a day with high-frequency moderate-intensity physical activity (M-day), and a day with high-frequency vigorous-intensity physical activity (V-day).

Results: Mean (± SD) 24-h EE for the C-day, the M-day, and the V-day was 2228 ± 143 kcal, 2816 ± 197 kcal, and 2813 ± 163 kcal, respectively. No significant difference was observed in 24-h EE between an M-day and a V-day. Mean EPEEs on the M-day and the V-day did not significantly contribute to increasing 24-h EE. Relative EPEEs to ΔPAEEs were 6.2 ± 13.9% (M-day) and 5.1 ± 9.2% (V-day). However, EPEE/24-h EE was negatively correlated with maximal oxygen uptake on the V-day ($r = -0.68$, $P = 0.02$), although no significant correlation between these variables was observed on the M-day ($r = -0.41$, $P = 0.21$).

Conclusions: These results suggest that EPEE has a small effect on 24-h EE in the course of normal daily activities, findings that do not support the proposition by the Institute of Medicine for estimating TEE. However, persons with low physical fitness levels could enhance EE as EPEE by increasing vigorous-intensity daily physical activity. *Am J Clin Nutr* 2008;87:1268–76.

INTRODUCTION

The prevalence of obesity has been increasing over the past few decades (1). The increase in weight or body fat is explained by a chronic imbalance between energy expenditure (EE) and energy intake. It is reported that regular exercise could play a major role in the control of body weight (2). Exercise (or physical activity) contributes to weight maintenance or weight reduction in several ways. First, thermogenesis is retained by maintaining fat-free mass. Second, EE is increased through exercise itself corresponding to work. Finally, increased EE may be induced by excess post-exercise oxygen consumption (EPOC) (3, 4).

EPOC is due to elevated oxygen consumption during the post-exercise period and consists of a rapid component and a prolonged component (5). The rapid component decays within approximately 1 h, followed by the prolonged component, which lasts for several hours. Many laboratories have examined the relation between exercise duration or intensity and the magnitude of EPOC (4, 6). According to Bahr and Sejersted (7), exercise intensity is curvilinearly related to EPOC. They suggested that exercise intensity must exceed 40% to 50% of maximal oxygen uptake ($\dot{V}O_{2max}$) to produce the prolonged component of EPOC, whereas 30% of $\dot{V}O_{2max}$ produces the rapid component of EPOC (7). Furthermore, it has been suggested that exercise duration has a linear relation to the magnitude of EPOC (8).

Physical activity thermogenesis can be divided into volitional exercise thermogenesis (sports and fitness-related activities) and nonexercise activity thermogenesis (9). It is generally accepted that obesity could be reduced through exercise or physical activity. That is, persons should increase total energy expenditure (TEE) by a range of physical activities including daily activities such as cleaning and gardening (10, 11). Levine et al (12) suggested that increasing nonexercise activity thermogenesis could be a strong contributor to preventing obesity. To support this proposition, it is important to verify the effects of additional EE after physical activity (elevated post–physical activity energy expenditure, or EPEE). There are no data on the effect of EPEE on 24-h EE under normal living conditions. Nevertheless, the Institute of Medicine proposed that 15% of EE as EPOC should be added to the additional physical activity energy expenditure (ΔPAEE) from sedentary conditions to estimate TEE, because adjustment for EPOC and dietary induced thermogenesis is expected to improve the underestimation of TEE by the factorial method compared with TEE measured by doubly labeled water (13, 14). Although it has been reported that these adjustments improved estimates of TEE (15, 16), they could be inappropriate

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for other studies in which TEE was not underestimated (17, 18). The purpose of this study was to examine the effects of EPEE on 24-h EE by modeling normal living conditions in a metabolic chamber.

SUBJECTS AND METHODS

Subjects

Eleven Japanese men participated in this study. All subjects were adults (≥20 y) and lacked chronic diseases that could affect metabolism or daily physical activity. They had not participated in regular intensive sports or physical activity for the past year but were able to complete a jogging regimen (8.0 km/h). The descriptive characteristics of the study subjects are presented in **Table 1**. Informed consent was signed by all subjects. The study protocol was approved by the Ethical Committee of the National Institute of Health and Nutrition.

Experimental design

Weight, height, and body composition were measured while the men were in a fasting state. Each subject completed a 24-h metabolic chamber measurement under 3 different protocols so that we could examine the effects of physical activity intensity: a control day (C-day); a day with high-frequency, moderate-intensity physical activity (M-day); and a day with high-frequency, vigorous-intensity physical activity (V-day). A test for peak oxygen uptake and metabolic chamber measurements were done at intervals of 2 to 3 d, but within 14 d to avoid metabolic influences from other protocols. We instructed the subjects to live under normal daily conditions during the measurement period (within 14 d) to maintain the same conditions, weight, and body composition for each measurement day. The order of the 3-d metabolic chamber measurements was randomly assigned to each subject.

Anthropometry and body composition

A digital scale was used to measure body weight to the nearest 0.1 kg while the subjects were dressed in light clothing. Barefoot standing height was measured to the nearest 0.1 cm by using a wall-mounted stadiometer. Body mass index was calculated as body weight (kg) divided by height squared (m^2).

Lean soft tissue mass, fat mass, and bone mineral content were measured by dual-energy X-ray absorptiometry (QDR-4500A scanner; Hologic, Waltham, MA). The subjects were positioned for whole-body scans according to the manufacturer's protocol. They lay in a supine position on the scanner table with their limbs close to their bodies. Fat-free mass was defined as the sum of lean soft tissue mass and bone mineral content.

TABLE 1
Physical characteristics of the subjects[1]

	$\bar{x}$ ± SD (range)
Age (y)	24.7 ± 5.8 (20–40)
Height (cm)	168.1 ± 3.9 (163.5–174.1)
Weight (kg)	64.5 ± 7.9 (50.6–74.0)
BMI (kg/m^2)	22.8 ± 2.8 (18.7–27.2)
Body fat (%)	16.4 ± 4.6 (10.3–22.8)
$\dot{V}O_{2peak}$ (L/min)	3.03 ± 0.57 (1.99–3.98)
$\dot{V}O_{2peak}$ ($mL \cdot min^{-1} \cdot kg^{-1}$)	47.3 ± 8.3 (29.2–59.1)

[1] $n = 11$. $\dot{V}O_{2peak}$, peak oxygen uptake.

Peak oxygen uptake

Peak oxygen uptake ($\dot{V}O_{2peak}$) was measured by use of an incremental running test on a treadmill (TREAD-MILL; Nishikawa Iron Works, Kyoto, Japan). The subjects warmed up at 160, 180, or 200 m/min at a fixed 0° grade for 5 min. The treadmill speed increased at a rate of 10 m/min for each successive minute of running until fatigue, defined as the speed at which the subject could no longer continue to keep up with the treadmill. Heart rate and rating of perceived exertion were monitored continuously. The rating of perceived exertion was obtained by using the modified Borg scale (19). Oxygen uptake was measured over 30-s intervals after the rating of perceived exertion reached 15. Subjects breathed through a low-resistance 2-way valve, and the expired air was collected in Douglas bags. Expired oxygen and carbon dioxide gas concentrations were measured by mass spectrometry (ARCO-1000A; Arco System, Kashiwa, Japan), and gas volume was determined by using a certified dry gas meter (DC-5; Shinagawa, Tokyo, Japan). For each measurement, the gas analyzer was initially calibrated by using a certified gas mixture and atmospheric air. The highest value of $\dot{V}O_2$ during the exercise test was designated as $\dot{V}O_{2peak}$.

Metabolic chamber

An open-circuit indirect metabolic chamber was used to evaluate 24-h EE, basal metabolic rate (BMR), and sleeping metabolic rate (SMR) (20, 21). Briefly, the respiratory chamber was an airtight room (20 000 L) equipped with a bed, desk, chair, TV with video deck, CD player, telephone, toilet, sink, and treadmill. The temperature and relative humidity in the room were controlled at 25 °C and 55%, respectively. The oxygen and carbon dioxide concentrations of the air supply and exhaust were measured by mass spectrometry. For each experiment, the gas analyzer (ARCO-1000A-CH; Arco System, Kashiwa, Japan) was initially calibrated by using a certified gas mixture and atmospheric air. The flow rate exhausted from the chamber was measured by pneumotachography (FLB1; Arco System). The flow meter was calibrated before each measurement, and the flow rate was maintained at ≈90 L/min (ATP). $\dot{V}O_2$ and carbon dioxide production ($\dot{V}CO_2$) were determined by the flow rate of exhaust from the chamber, and the concentrations of the inlet and outlet air of the chamber, respectively (20). EE was estimated from $\dot{V}O_2$ and $\dot{V}CO_2$ by using Weir's equation (22). The accuracy and precision of our metabolic chamber for measuring EE as determined by the alcohol combustion test was 99.8 ± 0.5% (mean ± SD) over 6 h and 99.4 ± 3.1% over 30 min.

Spontaneous physical activity was evaluated by using a motion-detecting system. The chamber had 2 independent sensors of passive infrared type (Matsushita Automation Controls Co, Ltd, AMP2009B01, Tokyo, Japan) that detected movement at speeds >7 cm/s. When at least 1 sensor detected movement, the movement was regarded as positive. The system provided percentage of time when movement was observed in each minute, and averaged spontaneous physical activity over each 15-min interval was used for analyses.

Design for timetables in the metabolic chamber

Physical activity level (PAL), which is calculated as TEE divided by BMR, has been categorized by the Institute of Medicine as low active (average: 1.5; range: 1.4–1.59), active (average: 1.75; range: 1.6–1.89), and very active (average: 2.2; range: 1.9–2.49) (14). The 2005 Japanese Dietary Reference Intakes reported similar categorization (23). Therefore, C-day was designed to correspond to a PAL of 1.4–1.59 including reference physical activity. On the basis of the C-day, we modeled M-day and V-day as follows: *1*) comparable PAL between M-day and V-day for comparing with these EPEEs, 2) PALs to include the normal human range, and *3*) actual percentages of low-, moderate-, and vigorous-intensity physical activity encountered in daily living (24, 25).

In the present study, we sought to model normal daily living in the metabolic chamber. Daily living activities consist of various physical activities, such as cleaning, cooking, washing, and gardening. However, it is very difficult to prescribe daily physical activity strictly, as well as to continue them for extended periods of time. Therefore, daily physical activity was substituted as follows: slow walking [3.2 km/h, 2.5 metabolic equivalents (METs)] as low-intensity physical activity, brisk walking (5.6 km/h, 3.8 METs) as moderate-intensity activity, and jogging (8.0 km/h, 8.0 METs) as vigorous-intensity activity (26). Note that physical activities in the course of daily living are carried out at high frequencies, but are relatively short in duration. For that reason, each activity was limited to a period of 15 min, which is the minimum duration required by our instrument to measure EE with high accuracy.

The schedules in the metabolic chamber are shown in **Table 2**. The subjects entered the chamber at 1750 and stayed until 1805 the next day. Sampling data were collected between 1800 and

TABLE 2
Timetables for each modeling day in the metabolic chamber[1]

Time	C-day	M-day	V-day
1750	Entry into a room	Entry into a room	Entry into a room
1800	Sit quietly	Sit quietly	Sit quietly
1815		Walking (5.6 km/h)	Walking (5.6 km/h)
1830		Sit quietly	Sit quietly
1845	Dinner → Sit quietly	Dinner → Sit quietly	Dinner → Sit quietly
1930		Walking (5.6 km/h)	Walking (5.6 km/h)
1945		Sit quietly	Sit quietly
2000		Walking (5.6 km/h)	
2015		Sit quietly	
2100	Walking (3.2 km/h)	Walking (3.2 km/h)	Walking (3.2 km/h)
2130	Sit quietly	Sit quietly	Sit quietly
2215		Walking (5.6 km/h)	
2230		Sit quietly	
2245		Walking (5.6 km/h)	
2300		Sit quietly	
2400	Go to sleep	Go to sleep	Go to sleep
700	Get up → Basal metabolic rate	Get up → Basal metabolic rate	Get up → Basal metabolic rate
800	Sit quietly	Sit quietly	Sit quietly
815	Breakfast → Sit quietly	Breakfast → Sit quietly	Breakfast → Sit quietly
900		Walking (5.6 km/h)	Walking (5.6 km/h)
915		Sit quietly	Sit quietly
925	Stretching	Stretching	Stretching
930	Sit quietly	Walking (5.6 km/h)	Jogging (8.0 km/h)
945		Sit quietly	Sit quietly
1030	Walking (5.6 km/h)	Walking (5.6 km/h)	Walking (5.6 km/h)
1100	Sit quietly	Sit quietly	Sit quietly
1140	Stretching	Stretching	Stretching
1145	Sit quietly	Walking (5.6 km/h)	Jogging (8.0 km/h)
1200		Sit quietly	Sit quietly
1215		Walking (5.6 km/h)	
1230		Sit quietly	
1245	Lunch → Sit quietly	Lunch → Sit quietly	Lunch → Sit quietly
1355	Stretching	Stretching	Stretching
1400	Sit quietly	Walking (5.6 km/h)	Jogging (8.0 km/h)
1415		Sit quietly	Sit quietly
1455	Stretching	Stretching	Stretching
1500	Jogging (8.0 km/h)	Jogging (8.0 km/h)	Jogging (8.0 km/h)
1515	Sit quietly	Sit quietly	Sit quietly
1600		Walking (5.6 km/h)	Walking (5.6 km/h)
1615		Sit quietly	Sit quietly
1805	Exit from a room	Exit from a room	Exit from a room

[1] C-day, a control day; M-day; a day with high-frequency, moderate-intensity physical activity; V-day, a day with high-frequency, vigorous-intensity physical activity.

1800 (24 h). The subjects went to bed at 2400 and were gently awakened at 0700 (7 h). The mean metabolic rate during this period was used as the SMR. After getting up, the subjects were permitted to use the toilet and were required to return to bed immediately. Then, the subjects remained in a supine position without movement until 0800. BMR was determined as the mean metabolic rate between 0715 and 0800. Except for prescribed physical activity and using the toilet, the subjects were only permitted to carry out light activities in a sitting position, such as reading, writing, and viewing television. Sleeping was not permitted. Meals were given 3 times a day to provide the predicted BMR (23) multiplied by the estimated PAL of 1.75, as an intermediate value for C-day and M-day (or V-day) modeling. Ratios of protein to fat to carbohydrate in total energy intake per day were 18:20:62. The same meals were provided on each of the 3 d to unify dietary induced thermogenesis.

Calculation of elevated post–physical activity energy expenditure

We estimated EPEE on the M-day and the V-day as measured 24-h EE minus predicted 24-h EE without EPEE. Predicted 24-h EE without EPEE was obtained from a model based on the C-day with use of the factorial method (**Figure 1**). That is, 24-h EE without EPEE for M-day and V-day was predicted by the 24-h EE for the C-day plus the reference EE for brisk walking and jogging. The reference EEs for brisk walking (5.6 km/h) and jogging in this model were calculated from each activity during C-day. To calculate steady state values for EE for these activities, EE values for the first 3 min and the last 1 min during the 2 reference activities were removed, and mean EE in the remainder was extended to 15 min (27, 28). Furthermore, for comparing with relative EE as EPOC to additional physical activity energy expenditure (ΔPAEE) in the US and Canada DRI equation, ΔPAEE was calculated as the predicted 24-h EE without EPEE on the M-day or V-day minus the 24-h EE for the C-day.

Statistical analysis

We performed a power calculation ($\alpha = 0.05$ and $\beta = 0.80$) to determine whether the EPEE value corresponded to 15% of ΔPAEE, which was ≈100 kcal in our subjects. Data from previous observations showed that the SD for the 24-h EE measurement in our metabolic chamber is ≈75 kcal. From this power

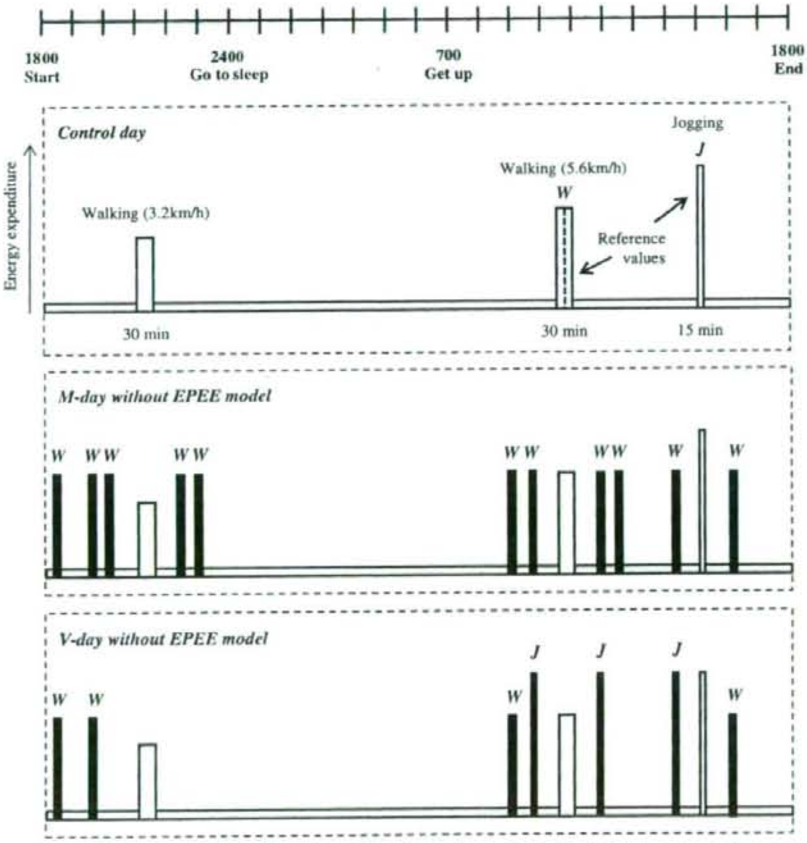

FIGURE 1. Model for predicting 24-h energy expenditure (EE) without elevated post–physical activity energy expenditure (EPEE). M-day, a day with high-frequency, moderate-intensity physical activity; V-day, a day with high-frequency, vigorous-intensity physical activity; W, reference energy expenditure for walking (5.6 km/h); J, reference energy expenditure for jogging; empty bar, actual energy expenditure by the prescribed physical activity for each day; filled bar, reference energy expenditure for brisk walking (5.6 km/h) or jogging.

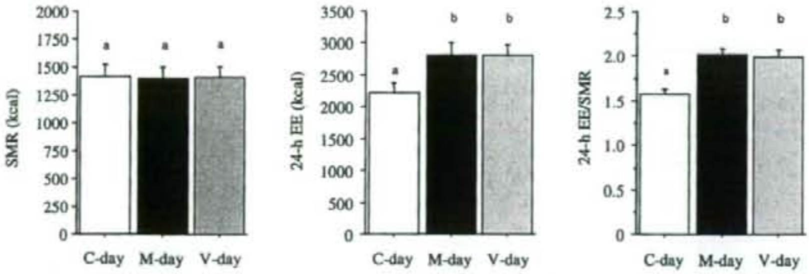

FIGURE 2. Sleeping metabolic rate (SMR), 24-h energy expenditure (24-h EE), and 24-h EE/SMR for each modeling day ($n = 11$). C-day, a control day; M-day; a day with high-frequency, moderate-intensity physical activity; V-day, a day with high-frequency vigorous-intensity physical activity. Error bars indicate SD. Bars with the same letter were not significantly different by one-way ANOVA with Scheffe's post hoc test ($P < 0.05$).

calculation, we determined that ≥9 subjects were needed. All values are presented as means ± SDs. Differences were considered to be statistically significant if the P value was <0.05. The SMR, 24-h EE, and 24-h EE/SMR values obtained in the 3 protocols were compared by one-way analysis of variance, and significant differences were analyzed by using Scheffe's post hoc test. Differences between actual 24-h EE and predicted 24-h EE without EPEE on M-day or V-day were assessed by the paired t test. Differences in any variable between M-day and V-day were assessed by the paired t test. Correlations between EPEE on the M-day or the V-day and $\dot{V}O_{2peak}$ or body composition were assessed by Pearson's correlation coefficients (r). All statistical analyses were performed by using SPSS version 14.0J for WINDOWS (SPSS Inc, Chicago, IL).

RESULTS

All subjects completed the 3-d metabolic chamber measurements according to prescribed timetables. The subjects' average total energy intake was 2685 ± 303 kcal, and this did not differ between the 3 d in each subject, because they ate all provided meals completely. Mean $\dot{V}O_{2peak}$ was 47.3 ± 8.3 $mL \cdot min^{-1} \cdot kg^{-1}$. Relative physical activity intensities for slow walking, brisk walking, and jogging were 21.4 ± 5.1%, 33.3 ± 7.0%, and 65.0 ± 14.1% of $\dot{V}O_{2peak}$, respectively.

Mean SMR, 24-h EE, and 24-h EE/SMR are shown in **Figure 2**. Twenty-four–hour EE for C-day, M-day, and V-day was 2228 ± 143 kcal, 2816 ± 197 kcal, and 2813 ± 163 kcal, respectively. No significant differences were observed in 24-h EE values between M-day and V-day, although there were significant differences between C-day and M-day or V-day. There were no significant differences between SMR values (or BMR values) for the 3-d periods for the subjects. CVs for SMR and BMR over 3 d were 1.0% and 1.7%, respectively. Twenty-four–hour EE/SMR for 3 d was 1.58 ± 0.06 for C-day, 2.02 ± 0.07 for M-day, and 2.00 ± 0.08 for V-day.

There were no significant differences between the measured 24-h EE value and the predicted 24-h EE value without EPEE for M-day or V-day (**Table 3**). Mean EPEE values for M-day and V-day were not significantly different. Relative EPEE values to measured 24-h EE values were 1.2 ± 2.7% and 1.0 ± 0.8%. Furthermore, relative EPEEs to ΔPAEEs were 6.2 ± 13.9% and 5.1 ± 9.2%, respectively.

Mean percentages of spontaneous physical activity during prescribed physical activity (slow walking, brisk walking, and jogging) for the 3 d were ≈100%. There were no significant differences in mean percentages of spontaneous physical activity for resting periods for the 3 d (C-day: 38.1 ± 9.0%; M-day: 43.8 ± 5.6%; V-day: 40.4 ± 8.2%).

The relations between EPEE/24-h EE and $\dot{V}O_{2peak}$ or fat-free mass for M-day or V-day are shown in **Figure 3** and **Figure 4**. EPEE/24-h EE for V-day was negatively correlated with $\dot{V}O_{2peak}$, whereas no significant correlation between these variables was observed for EPEE/24-h EE for M-day. As for the relation between EPEE/24-h EE or EPEE and fat-free mass, no significant correlations were observed for either M-day or V-day. Also, fat mass and body mass indexes were not significantly correlated with EPEE/24-h EE or EPEE for either day. The correlation coefficients for EPEE versus between-day SMR difference were 0.31 (NS) and 0.63 ($P < 0.05$) for M-day and V-day, respectively.

DISCUSSION

This investigation examined the effects of EPEE on 24-h EE by modeling normal living activities in a metabolic chamber.

TABLE 3

Elevated post–physical activity energy expenditure (EPEE) for the M-day and the V-day[1]

	M-day[2]	V-day[2]
Predicted 24-h EE without EPEE (kcal)[3]	2781 ± 185	2784 ± 167
Measured 24-h EE (kcal)	2816 ± 197[4]	2813 ± 163[4]
Δ PAEE (kcal)[5]	553 ± 53	556 ± 49
EPEE (kcal)[6]	35 ± 78	29 ± 53
EPEE/measured 24-h EE × 100 (%)	1.2 ± 2.7	1.0 ± 0.8
EPEE/Δ PAEE × 100 (%)	6.2 ± 13.9	5.1 ± 9.2

[1] All values are $\bar{x}$ ± SD. M-day, a day with high-frequency, moderate-intensity physical activity; V-day, a day with high-frequency, vigorous-intensity physical activity; 24-h EE, 24-h total energy expenditure; Δ PAEE, additional physical activity–induced energy expenditure.

[2] There was no significant difference in each variable between the M-day and the V-day by paired t test ($P < 0.05$).

[3] Values were calculated on the basis of a control day.

[4] There was no significant difference between predicted 24-h EE without EPEE and measured 24-h EE on the M-day or the V-day by paired t test ($P < 0.05$).

[5] Predicted 24-h EE without EPEE minus control day.

[6] Measured 24-h EE minus predicted 24-h EE without EPEE.

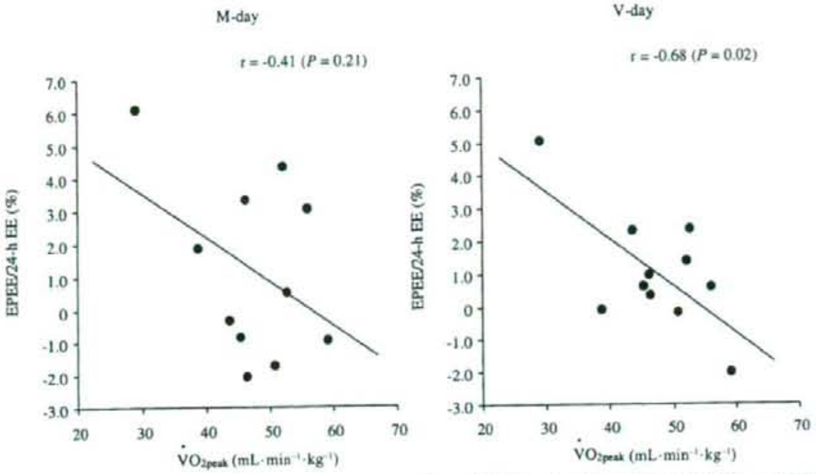

FIGURE 3. Relation between elevated post–physical activity energy expenditure (EPEE) and peak oxygen uptake ($\dot{V}O_{2peak}$) for the M-day (a day with high-frequency, moderate-intensity physical activity) and the V-day (a day with high-frequency, vigorous-intensity physical activity). 24-h EE, 24-h energy expenditure.

There was no significant additional EE as EPEE in total 24-h EE when the subjects spent 24 h in a metabolic chamber under conditions that were ≈2.0 for 24-h EE/SMR (similar to PAL) for high-frequency, moderate-intensity or vigorous-intensity physical activity. However, subjects with low physical fitness may produce significant additional EE as EPEE by increasing daily vigorous-intensity physical activity.

Although EPOC has been studied in depth, most analyses examined the effects of EPOC after a single bout of exercise (4, 6). However, if one is to understand the effects of EPOC in weight reduction or maintenance, it is important to investigate the magnitude of EPOC after physical activity under normal living conditions. Previous studies suggested that EPOC after a single bout of exercise was generated in proportion to exercise duration, when exercise intensity exceeds about 50–60% $\dot{V}O_{2max}$ (6–8). Almuzaini et al (29) reported that dividing a 30-min exercise session into 2 parts significantly increased the magnitude of EPOC. However, this study was limited to the 40-min period after exercise, and the difference between EPOC values was only ≈10 kcal. Normal daily activity conditions evidently differ from those experimental conditions, because in the normal course of daily activity, people engage in a wide range of physical activity, the intensity of which vary from light to vigorous (26). The duration of most of these activities

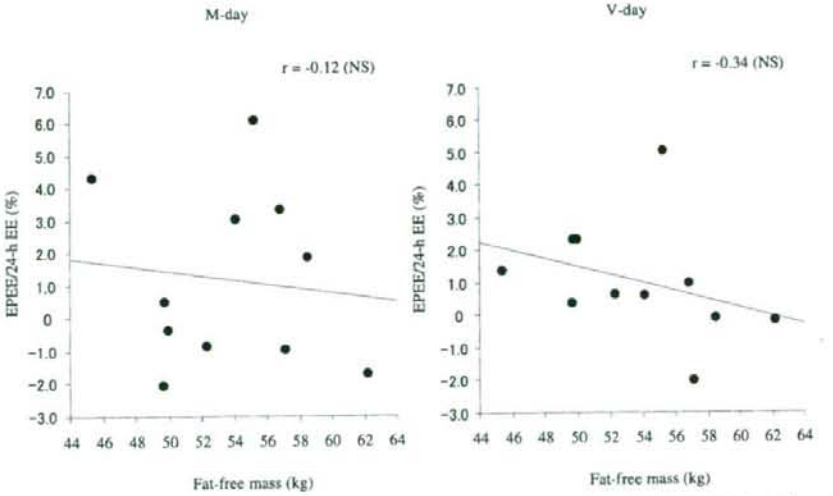

FIGURE 4. Relation between elevated post–physical activity energy expenditure (EPEE) and fat-free mass for the M-day (a day with high-frequency, moderate-intensity physical activity) and the V-day (a day with high-frequency, vigorous-intensity physical activity). 24-h EE, 24-h energy expenditure. There were no significant correlations between EPEE and fat-free mass for any day ($P < 0.05$).

and the intervals between moderate-to-vigorous physical activity are short, but their frequencies are high. This situation requires examination of the effects of EPEE (similar to, but a broader component than EPOC) on 24-h EE under normal activity conditions.

If significant EPEE by combined physical activity in daily living exists, one reason might be that the total duration of all physical activity amounted to several hours per 24 h, even though each activity was short. Furthermore, short intervals between physical activities with high frequencies may produce higher EPEE than the EPEE induced by a prolonged, single bout of exercise. However, the present study failed to identify any significant additional EE as EPEE in the 24-h EE. That is, multiplying short-duration physical activities with short intervals between activities may not contribute much toward increasing the 24-h EE, compared with prolonged physical activity, even if persons perform these short-duration physical activities with high frequencies during a 24-h period. The Institute of Medicine has proposed that 15% of EE as EPOC to ΔPAEE from sedentary condition should be added in estimating total energy expenditure (14). This proposition is based on the report by Bahr et al (13), which compared EPOC magnitudes between 20, 40, and 80 min of ergometer exercise at 70% $\dot{V}O_{2max}$. As a result, each EPOC was ≈15% of exercise-induced EE for 12 h after the exercise sessions. However, this evidence was obtained from a single-bout trial. In our experimental design, normal daily activity conditions were modeled, and EPEE resulted in 6.2 ± 13.9% (M-day) and 5.1 ± 9.2% (V-day) of ΔPAEE. Therefore, the equation estimating TEE proposed by the Institute of Medicine, which adds 15% EE as EPOC to ΔPAEE, would overestimate 24-h EE.

Previous studies using a single round of exercise suggest that one possible explanation for not observing significant EPEE in daily activity was that many daily activities do not reach the intensity threshold of 50–60% $\dot{V}O_{2max}$ (7, 8). We adopted brisk walking (3.8 METs) as a moderate-intensity physical activity and jogging (8.0 METs) as a vigorous-intensity physical activity. Note that Pate et al (30) have defined that moderate-intensity physical activity ranged from 3 to 6 METs and vigorous-intensity physical activity was >6 METs. The relative exercise intensities of brisk walking and jogging were 33.3 ± 7.0% and 65.0 ± 14.1%, respectively. Brisk walking did not reach 50–60% $\dot{V}O_{2max}$ as the intensity threshold for producing EPOC. On the other hand, Melanson et al (31) reported that if energy expenditures were matched between high-intensity exercise and low-intensity exercise with well-controlled conditions in a metabolic chamber, no significant difference was observed in 24-h EE values between these 2 conditions. Saris and Schrauwen (32). reported that in obese subjects, no significant differences in 24-h EE values were observed between the day with high-intensity interval exercise and the day with low-intensity endurance exercise when the exercise sessions were equicaloric in energy expenditure. From our results and previous studies, it appears that exercise or physical activity intensity does not influence the contribution of EPOC to 24-h EE. However, a significant difference of EPOC magnitude may be found between high- and low-intensity exercise when one measures EPOC within several hours of a single-bout trial.

The inclusion (or lack thereof) of oxygen deficit in calculations of EPOC may contribute to discrepancies among studies. Most studies with a single-bout trial compared EPOC to oxygen consumption during an exercise bout (4, 6), in which case oxygen deficit is not taken into account. On the other hand, we discuss EPEE without EE equivalent to oxygen deficit, by extrapolating steady state EE (excluding EE in the first 3 min and the last 1 min) to the whole EE in each physical activity period. Although total EPOC is greater than oxygen deficit, a large part of the rapid component of EPOC is explained by oxygen deficit during the exercise (5). If we consider the extra energy expenditure due to exercise or physical activity in 24-h EE, such as the estimation of TEE in the Institute of Medicine (14), EE corresponding to oxygen deficit should be excluded. However, the study by Bahr et al (13) discussed the contribution of EPOC to EE during an exercise bout, so adding 15% as EPOC to ΔPAEE should lead to overestimation of TEE.

Although EPEE did not contribute to a significant increase in 24-h EE in the present study, EPEE/24-h EE for V-day was significantly correlated with $\dot{V}O_{2peak}$. That is, a person with low fitness may generate more EPEE by increasing daily physical activity. Short and Sedlock (33) reported that even though EE during exercise in trained subjects was much higher than that in untrained subjects, EPOC was similar between the groups if different subjects exercised at the same relative intensity of 70% $\dot{V}O_{2peak}$. When compared with subjects with higher $\dot{V}O_{2max}$, those with lower oxygen uptake produced more lactate, a major biochemical component of EPOC (34). Therefore, a negative relation between $\dot{V}O_{2peak}$ and EPEE/24-h EE observed in the present investigation is reasonable.

Trained individuals have better thermoregulatory capacities than do untrained individuals because physical training enhances the sweating mechanism at a given level of the central sweating drive (35). Therefore, elevated body temperature in untrained individuals could last longer than in trained individuals (36). These phenomena require extra oxygen consumption for recovery. Therefore, fitness level may contribute to the magnitude of EPEE. On the other hand, there was no significant relation between EPEE/24-h EE for the M-day and $\dot{V}O_{2peak}$. In other words, it is assumed that exercise duration (with relative intensity over the threshold for producing the slow component of EPOC) may be longer in less fit subjects than in fit subjects, leading to more slow-component production in less fit subjects. However, the relative intensities of the 3 physical activities in this study were different in individuals, because these physical activities were prescribed by the same absolute intensities. Interestingly, EPEE was negative on both the M-day and the V-day in several subjects. One possible reason may have been interday variations in resting metabolic rate. In the present study, SMR values on M-day or V-day were lower than the SMR values on C-day in some cases, and the correlation coefficients for EPEE versus between-day SMR difference were 0.31 and 0.63 on M-day and V-day, respectively. Therefore, the negative values of EPEE may reflect interday variations in resting metabolic rate. In addition, people may compensate for an increase in EE due to activity by decreasing their nonexercise EE (37). In the present study, the total duration of prescribed physical activity was 240 min on the M-day. That is, the duration on the M-day was 60 min longer than on the V-day. Therefore, the total duration or frequency of physical activity during the day may affect the observed decrease in nonexercise EE.

In the present study, there were no significant correlations between EPEE for M-day (or V-day) and physical status (fat-free mass, fat mass, and body mass index). Crommett and Kinzey (38) have reported similar results. Although body composition may not influence EPEE, many obese persons are untrained and have a low level of fitness. Therefore, our results suggest that obese persons with a low fitness level could expect additional EE as EPEE to assist in weight reduction, provided that they perform high-frequency, relatively vigorous physical activity in the course of daily living. Otherwise, persons with a high fitness level may not expect significant EPEE through daily physical activity, because daily activity is difficult to adjust to high intensity, like typical exercise activity.

This study had several limitations. First, we could not measure actual daily physical activity because we conducted the measurements in a metabolic chamber. Additionally, the duration of each physical activity under normal living conditions may be shorter than 15 min in many cases, whereas 15 min was the minimum duration of activity required for accurate measurement values in this study. Even though we gathered data under well-controlled conditions, our experimental protocol could not detect any EPEE on the control day. However, control day EPEE values should be added to the calculated EPEE values on M-day and V-day. Although we believe that control day EPEE values would not be large, the actual ΔPAEE in normal daily living may thus be slightly higher than our calculated results. Furthermore, future studies are needed to clarify the association between fitness and EPEE, because inclusion of a single subject in our data set, the one with the lowest fitness, strongly contributed to the significant (but modest) inverse association observed between these variables.

In conclusion, we found that EPEE has a only small effect on 24-h EE under normal living conditions. Therefore, adding 15% EE as EPOC to ΔPAEE, in accord with the Institute of Medicine recommendation for estimating TEE, would overestimate 24-h EE. However, persons with a low physical fitness level may produce additional EE as EPEE by increasing relatively vigorously intense daily living physical activity.

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連載

運動・身体活動と公衆衛生(5)
「日常生活における生活活動評価の重要性」

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1. 「健康づくりのための運動基準2006」の特徴

厚生労働省は，2006年に「健康づくりのための運動基準2006」および「健康づくりのための運動指針2006（エクササイズガイド2006）」を策定した。その特徴の一つは，“運動”と“身体活動”それぞれについて，生活習慣病の予防に必要な基準値を提示したことである。海外では，CDC/ACSM が1995年に，“運動”から“身体活動”を対象に切り替えたガイドラインを出している1)。しかし，日本のガイドラインで，運動に限らない身体活動全体をここまで重視したのは，今回が初めてである。

なお，身体活動とは，「骨格筋の活動により安静時よりも多くのエネルギー消費を伴う身体の状態」であり2)，とくに健康増進や体力の維持・増進を目的とした計画的・組織的で継続性のある“運動”と，それ以外の余暇・家事・仕事からなる“生活活動”に大別できる。

2. 身体活動によるエネルギーは，一日当たりのエネルギー消費量の平均30％程度

一日当たりのエネルギー消費量（total energy expenditure：TEE）を基礎代謝量で除して得られる身体活動レベル（physical activity level：PAL）は，一般におよそ1.4から2.2の幅に分布する3)。PAL は，食事に伴う熱産生（食事誘発性体熱産生）も含んでいるものの，主に身体活動量によって決定される。日本人における PAL の平均値である1.75から逆算すると，基礎代謝量は TEE の約60％に相当する。食事誘発性体熱産生を TEE の約10％と仮定すると，身体活動によるエネルギーは，平均30％程度（PAL の1.4から2.2に対応する範囲：およそ20～45％）に相当する。また，一般に PAL の標準偏差は0.2を越える。標準的な体格であれば基礎代謝量は1,400 kcal/日程度なので，このばらつきはおおよそ±300 kcal/d（標準偏差）に相当する。測定誤差を考慮するために，分散の半分が真の個体間活動と仮定しても，おおよそ±220 kcal/d となる。

3. 運動が一日当たりのエネルギー消費量に占める割合は小さい

運動習慣によって大きな個人差はあるものの，運動が TEE に占める割合は，一般に小さい。最も多い運動形態はウォーキングであるが，たとえば，運動として30分間の速歩を週5回実施しても，それによって付加されるエネルギーは，一日当たりに換算するとおよそ$(4-1)\times 30\times 5\div 7\fallingdotseq 65$ kcal にしかならない。これは，TEE のわずか3％程度である。

しかも，国民健康・栄養調査4)によると，1回30分以上の運動を週2日以上実施している人は，およそ30％程度でしかない。30分未満の運動あるいは週1回の運動を実施している人がいる一方で，上記の30％の人の何割かは，週2回程度しか運動を実施しておらず，残りの5日は運動を実施していないかもしれない。

こうして考えると，TEE に占める運動の割合は，平均して3％かそれ以下である可能性は非常に高いと考えられる。身体活動のエネルギーが TEE の約30％程度であるので，「身体活動の大部分は，運動以外の身体活動である」と考えられる。

4. 運動以外の身体活動（NEAT）とは？

運動以外の身体活動（Nonexercise activity thermogenesis：NEAT）は，必ずしも新しい概念ではない。しかし，NEAT に関する論文5)が1999年に Science に掲載されたのをきっかけに，国際的に注目されるようになっている。

NEAT は，姿勢の保持（座位や立位を含む）や，掃除・洗濯を含む家事，買い物・通勤などにおける歩行，庭仕事などの余暇活動，仕事中における荷物の運搬など，低～中強度を中心に様々な活動が含まれる6)。

NEAT の構成要素として fidgeting（そわそわ動き）も含まれる。ヒューマンカロリメーター（エネルギー代謝測定室）内でも100～800 kcal/日の NEAT が報告されている7)。日常生活については，

この2～3倍程度のバラツキとなるが，両者には有意な相関がみられる8,9)。

様々な対象者におけるDLW法の結果に基づいて推定すると，NEATは最大で一日に2,000 kcal程度にまでおよぶと考えられる6)。

5. NEATが肥満予防に果たす役割

NEATは，平均値や変動幅が大きいだけでなく，肥満にも関与している可能性が示唆されている。先に述べた論文で，Levineは，1日1,000 kcal/日もの過食を8週間続けるという実験を行った5)。その1,000 kcal/日がどのように利用されたかを，身体組成やエネルギー消費量の測定値から推定した。その結果，平均して39%が体脂肪に変わっていたが，その次に割合が大きかったのは，運動以外の身体活動であった。また，この過食実験により体脂肪が増加した割合に大きな個人差がみられたが，この個人差と関連していたのは，基礎代謝量や食事誘発性体熱産生の変化量ではなく，NEATの変化量であった。すなわち，過食した時に，NEATが増加するかどうかによって太るかどうかが決定されるという結果であった。

Levineは，その後，肥満者と非肥満者で，日常生活における姿勢とエネルギー消費量を比較した10)。その結果，肥満者は平均して座位の時間が約2時間半長く，それによるエネルギー消費量の差は352 kcal/日に及ぶと推定している。また，肥満者がやせたり非肥満者が太ったりしてもその傾向は変わらなかったため，遺伝的に姿勢が決定されているのではないかと考察している。

最近，客観的な測定装置（IDEEA）を用いて，日常生活における姿勢別の所要時間を肥満女性と非肥満女性との間で比較した結果が報告された11)。その結果も，Levineらと同じく，肥満者の座位時間が非肥満者より約2.5時間/日多いというものであった。以上のように，NEATも肥満と関連している可能性がある。

一方，高齢者において，二重標識水（doubly labeled water：DLW）法により評価した身体活動量が多いほど総死亡率が低かったという縦断的な研究結果も，最近報告されている12)。

6. 歩行以外の身体活動

現時点では，身体活動，とくにNEATを正確に定量化することは難しい6,13)。その原因の一つとして，歩行以外の身体活動が，これまで十分に考慮されなかったことがある。

ヒューマンカロリメーターで運動を含まない生活を送ると，PALは1.3～1.4程度である14)が，1.75程度のPALとなるようにするには，約80 m/分程度の普通歩行を約3時間程度行う必要がある15)。しかし，標準的な歩数から推定すると，1日に歩いている時間（室内歩行を含む）は1～1.5時間程度にしかならない。したがって，日常生活においては，必須活動と歩行以外に，残りの1.5～2時間程度の普通歩行に相当するだけの身体活動があるはずである。現在市販されている歩数計タイプの加速度計を用いた場合，DLW法と比較して，平均しておよそ20%（10～35%以上）もTEEが過小評価される13)のは，こうしたことが主な理由であると考えられる。

ちなみに，若年男性におけるTEEの平均は約2,500 kcal/日である。また，先に述べたように，身体活動に要するエネルギーは，平均してTEEの約30%である。したがって，歩行以外の身体活動に要するエネルギーは，おおよそ500 kcal/日，身体活動のうちの約2/3に相当すると考えられる。これだけのエネルギーを見過ごすのは問題だと思われる。

7. 歩行以外の身体活動の評価

このように，運動や歩行より絶対量やバラツキの大きいNEAT，あるいは歩行以外の身体活動も重要であると考えられる。これまでの加速度計では歩行と歩行以外を区別できず，歩行・走行で検討した加速度からの推定式は，家事などの生活活動（lifestyle activity）を過小評価する傾向にあった16)。その結果として，歩行時の加速度とエネルギー消費量との関係式からTEEを推定すると過小評価するのに対し，生活活動から得られた関係式を用いると，必ずしもそうではないという報告もある17)。

その解決策が模索されているが，我々は，3次元加速度計を用いて，両者を区別する方法を検討してきた。歩行・走行時は，速度・強度が大きくなるほど，特に垂直方向の加速度が大きくなる。それに対して，生活活動では，水平方向に比べ垂直方向の値はそれほど大きくならない。そこで，垂直方向と水平方向の加速度の比を用いて，歩行・走行タイプと生活活動タイプを判別する方法を考案した18,19)。その後，オムロンヘルスケア㈱と共同で，より優れた判別法を見出し，製品化に成功した（Active style Pro HJA-350IT）。これは，歩行では身体の傾斜の変化がないのに対し，生活活動ではあることを利用したものである。これを用いると，先に述べたTEEの過小評価もほぼ解決する。

このように，加速度計により身体活動強度を正確に推定するためにも，また，身体活動のタイプを客観的に評価するためにも，歩行と歩行以外の身体活

動を区別することは重要である。

8. NEATの客観的な評価の必要性

質問紙法は，二重標識水（DLW）法などの妥当基準と比較すると，平均値が一致することはあるものの，多くの場合，相関は弱い20,21)。したがって，集団の平均値を推定することは可能であっても，個人間差をみるには適当ではない。そのため，たとえば身体活動量と生活習慣病のリスクとの関連を検討するような場合には，Wareham ら22)や Blair ら23)も述べているように，質問紙法よりは，加速度計や歩数計，DLW 法などの，より客観的で正確な方法を用いる方が望ましい。もちろん，これらによる身体活動量評価の妥当性が保証されていることが前提であるし，質問紙法の更なる工夫も必要である。

まとめ

以上，本稿をまとめると以下の通りである。

- 身体活動の大部分は，運動ではなく，運動以外の身体活動（NEAT）である。
- NEATの個人間差は非常に大きい。
- 歩行より歩行以外の身体活動の方が多い。
- したがって，従来関心がもたれてきた運動や歩行だけでなく，NEATや「歩行以外の身体活動」にも着目する必要がある。
- 質問紙調査では個人間差を十分にとらえられないので，疫学調査でも，加速度計や歩数計，DLW法など，なるだけ客観的かつ正確な方法を用いる必要がある。

正確な方法を用いて調査することができたら，「やはりNEATより運動が，あるいは歩行以外の活動より歩行が重要だ」という結果が得られるのかもしれない。しかし，絶対量や個人差が大きいにも関わらず，NEATおよび歩行以外の身体活動について，これまで十分に注目されてこなかっただけに，今後は，これらの評価法や肥満・生活習慣病との関連を検討していく必要がある。

次回は，「運動行動からみた健康支援；運動疫学から社会疫学への展開」について，九州大学健康科学センターの熊谷秋三先生にご報告いただく予定です。

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