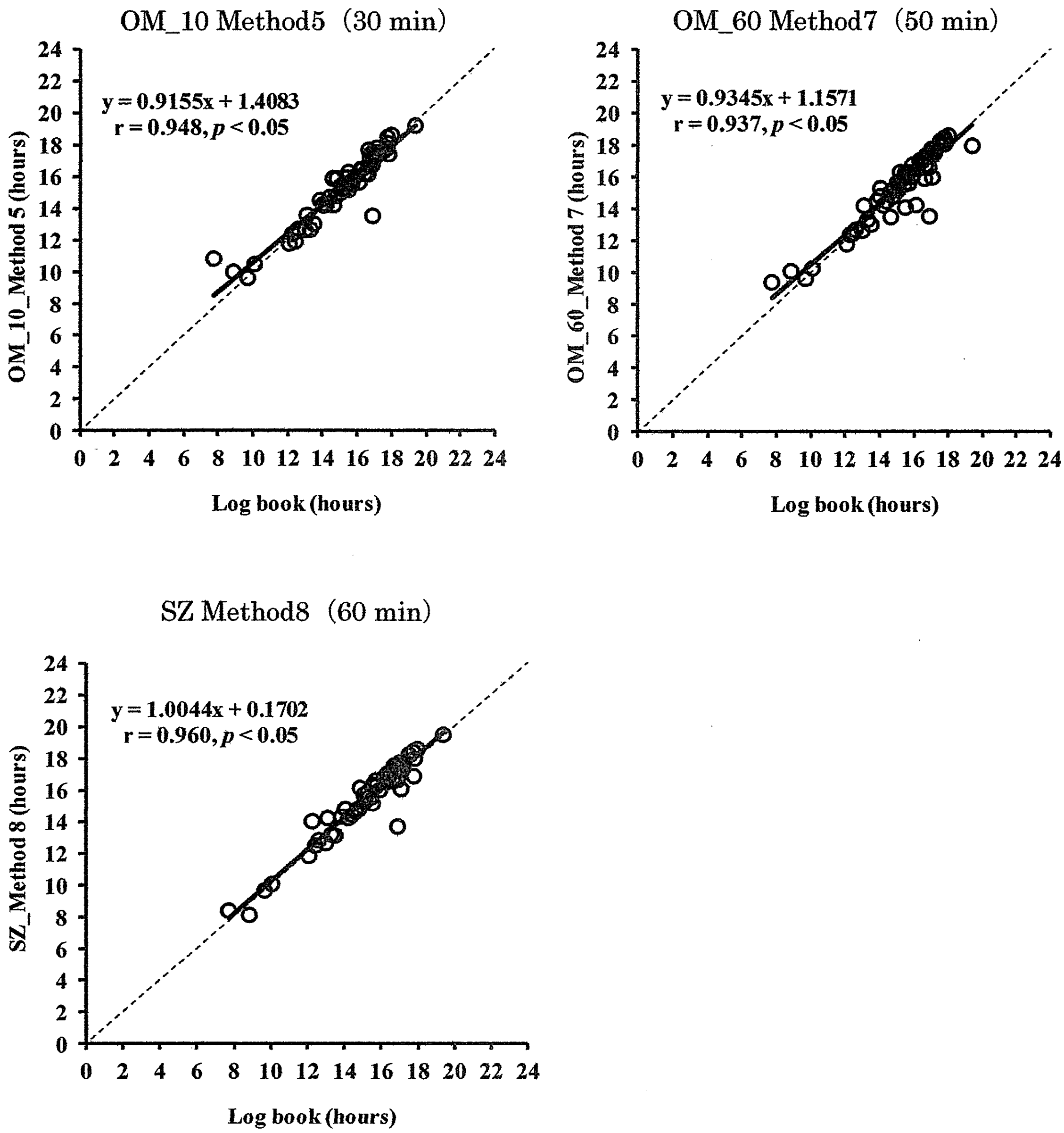

Fig. 1. Relationship between Method 0-12 and Log Book.

dashed line (---); identity line.

OM_10: Omron accelerometer 10 sec, OM_60: Omron accelerometer 60 sec, SZ: Suzuken accelerometer

Ⅲ．研究成果の刊行に関する一覧表

書籍

著者氏名	論文タイトル名	書籍全体の編集者名	書　籍　名	出版社名	出版地	出版年	ページ
なし							

雑誌

発表者氏名	論文タイトル名	発表誌名	巻号	ページ	出版年
田中茂穂	エネルギー消費量とその測定法　特集：必要エネルギー量の算出法と投与の実際	静脈経腸栄養	24(5)	1013-1019	2009
Tanaka C、Tanaka S	Daily physical activity in Japanese preschool children evaluated by triaxial accelerometry: the relationship between period of engagement in moderate-to-vigorous physical activity and daily step counts.	J Physiol Anthropol	28(6)	283-288	2009
Oshima Y、Kawaguchi K、Tanaka S、Ohkawara K、Hikihara Y、Ishikawa-Takata K、Tabata I	Classifying household and locomotive activities using a triaxial accelerometer.	Gait Posture	31(3)	370-374	2010
田畑泉	エネルギー．特集　日本人の食事摂取基準（2010年版）	臨床栄養	115(3)	255-260	2009
Inoue S、Murase N、Shimomitsu T et al	Association of physical activity and neighborhood environment amon Japanese adults.	Prev Med,	48	321-325	2009
Ishii K、Inoue S、Ohya Y、et al	Socioemographic variations in perceptions of barriers to exersise among Japanese adults.	J Epidemiol	19	161-168	2009
Ishikawa-Takata K, Naito Y, Tanaka S, Ebine N, Tabata I.	Use of doubly labeled water to validate a physical activity questionnaire developed for the Japanese population	J Epidemiol	21(2)	114-121	2011

Taguri E, Tanaka S, Ohkawara K, Ishikawa-Takata K, Hikihara Y, Miyake R, Yamamoto S, Tabata I	Validity of physical activity indexes for adjusting energy expenditure for body size: Do index depend on body size?	Journal of Physiological Anthropology	29(3)	109-117	2010
Miyachi M, Yamamoto K, Ohkawara K, Tanaka S	METs in adults while playing active video games: a metabolic chamber study	Medicine and Science in Sports and Exercise	42(6)	1149-1153	2010
Inoue S, Ohya Y, Odagiri Y, Takamiya T, Ishii K, Kitabayashi M, Suijo K, Sallis JF, and Shimomitsu T.	Association between Perceived Neighborhood Environment and Walking among Adults in 4 Cities in Japan	J Epidemiol	20(4)	277-286	2010
Inoue S, Ohya Y, Odagiri Y, Takamiya T, Kamada M, Okada S, Tudor-Locke C, and Shimomitsu T.	Characteristics of Accelerometry Respondents to a Mail-Based Surveillance Study	J Epidemiol	20(6)	446-452	2010
Park J, Ishikawa-Takata K, Tanaka S, Hikihara Y, Ohkawara K, Watanabe S, Miyachi M, Morita A, Aiba N, Tabata I	Relation of body composition to daily physical activity in free-living Japanese adult women	Br J Nutr	106(7)	1117-1127	2011
Park JH, Ishikawa-Takata K, Tanaka S, Mekata Y, Tabata I	Effects of walking speed and step frequency on estimation of physical activity using accelerometers	J Physiol Anthropol	30(3)	119-127	2011
Miyake R, Tanaka S, Ohkawara K, Ishikawa-Takata K, Hikihara Y, Taguri E, Kayashita J, Tabata I	Validity of predictive equations for basal metabolic rate in Japanese adults	J Nutr Sci Vitaminol	57(3)	224-232	2011
Miyake R, Ohkawara K, Ishikawa-Takata K, Morita A, Watanabe S, Tanaka S	Obese Japanese adults with Type 2 diabetes have higher basal metabolic rates than non-diabetic adults	J Nutr Sci Vitaminol	57(5)	348-354	2011

Tudor-Locke C, Craig CL, Beets MW, Belton S, Cardon GM, Duncan S, Hatano Y, Lubans DR, Olds TS, Raustorp A, Rowe DA, Spence JC, Tanaka S, Blair SN	How Many Steps/day are Enough? For Children and Adolescents	Int J Behav Nutr Phys Act	8(1)	78	2011
Tudor-Locke C, Craig CL, Brown WJ, Clemes SA, De Cocker K, Giles-Corti B, Hatano Y, Inoue S, Matsudo SM, Mutrie N, Oppert JM, Rowe DA, Schmidt MD, Schofield GM, Spence JC, Teixeira PJ, Tully MA, Blair SN	How Many Steps/day are Enough? For Adults	Int J Behav Nutr Phys Act	8(1)	79	2011
Inoue S, Ohya Y, Tudor-Locke C, Tanaka S, Yoshiike N, Shimomitsu T	Time trends for step-determined physical activity among Japanese adults	Med Sci Sports Sci	43(10)	1913-1919	2011
Ohkawara K, Ishikawa-Takata K, Park J, Tabata I, Tanaka S	How much locomotive activity is needed for an active physical activity level: analysis of total step counts	BMC Research Notes	4	512	2011
田中茂穂	日本人の代謝基準値の再評価	体育の科学	61(8)	576-582	2011
Inoue S, Sugiyama T, Takamiya T, Oka K, Owen N and Shimomitsu T	Television viewing time is associated with overweight/obesity among older adults, independent of meeting physical activity and health guidelines	J Epidemiol	22(1)	50-56	2012

Liao Y, Harada K, Shibata A, Ishii K, Oka K, Nakamura Y, Sugiyama T, Inoue S, Shimomitsu T	Joint associations of physical activity and screen time with overweight among Japanese adults	Int J Behav Nutr Phys Act	8	131	2011
Inoue S, Ohya Y, Odagiri Y, Takamiya T, Suijo K, Kamada M, Okada S, Tudor-Locke C, Shimomitsu T	Sociodemographic determinants of pedometer-determined physical activity among Japanese adults	Am J Prev Med	40	566-571	2011
Kamada M, Kitayuguchi J, Shiwaku K, Inoue S, Okada S, Mutoh Y	Differences in association of walking for recreation and for transport with maximum walking speed in an elderly Japanese community population	J Phys Act Health	8	841-847	2011
Liao Y, Harada K, Shibata A, Ishii K, Oka K, Nakamura Y, Inoue S, Shimomitsu T	Perceived environmental factors associated with physical activity among normal-weight and overweight Japanese men	Int J Environ Res Public Health	8	931-943	2011
Ohkawara K, Oshima H, Hikihara Y, Ishikawa-Takata K, Tabata I, Tanaka S	Real-time estimation of daily physical activity intensity by triaxial accelerometer and a gravity-removal classification algorithm	British Journal of Nutrition	105	1681-1691	2011

Ⅳ. 研究成果の刊行物・別刷

総論　エネルギー消費量とその測定方法*

keywords：エネルギー消費量、基礎代謝量、身体活動レベル

田中茂穂　Shigeho TANAKA, Ph.D.

◆独立行政法人国立健康・栄養研究所　健康増進プログラム(エネルギー代謝プロジェクトリーダー)
Health Promotion and Exercise Program, National Institute of Health and Nutrition

総エネルギー消費量は、基礎代謝量と食事誘発性体熱産生、身体活動によるエネルギー消費量に分けられる。基礎代謝量は、標準的な日本人において約6割を占めるが、体格・身体組成からある程度推定できる。ただし、ハリス・ベネディクトの式では、若い年代をはじめ、成人全体において、過大評価する傾向がみられる。一方、身体活動、特に運動以外の身体活動によるエネルギー消費量(NEAT)には、同じ体格でも大きな個人差がみられる。総エネルギー消費量を推定するための方法としては二重標識水(DLW)法がベストの方法とされているが、現実的には、それぞれの方法の特徴をふまえた上で、加速度計法あるいは生活活動記録などを用いることとなる。

I. 総エネルギー消費量(total energy expenditure；以下、TEEと略)の内訳

一日当たりのエネルギー消費量＝TEEは、以下のような構成要素に分けられる。

1) 基礎代謝量(basal metabolic rate;以下、BMRと略)

人が生きていく上で必要な最小限のエネルギーを評価しようという意図から出てきた概念である[1)2)]。一般に、以下の条件で測定される。

・約12時間以上の絶食
・安静仰臥位で、筋の緊張を最小限にした状態
・快適な室温で、心身ともにストレスの少ない覚醒状態

BMRは測定前日から、測定実施場所に宿泊して測定をすることもあるが、当日の朝、測定実施場所に移動し、十分な安静(30分以上)を保った後測定されることも多い[1)2)]。

一般に、BMRがTEEの中で最も大きな構成成分である。TEEをBMRで割った身体活動レベル(physical activity level；以下、PALと略)の標準値は、日本人の食事摂取基準(2010年版)[3)]においても、また、欧米人においても[4)]1.75程度であるので、逆算すると、BMRはTEEの約60%程度を占めると考えられる。

BMRは、筋肉の緊張を最小限にした状態で測定される。そのため、除脂肪量の約半分を占める筋肉がBMR測定時に消費するエネルギーは20%程度で、その他、脳、肝臓、心臓、腎臓等の内臓も大きな割合を占めている[5)](表1)。したがって、体重、中でも除脂肪量がわかれば、BMRをより高精度で推定することが可能となる。BMRは一般に女性

表1　安静時における臓器別エネルギー消費量(reference man).

	重量(kg)	代謝率(kcal/kg/day)	代謝量の割合(%)
骨格筋	28	13	21.6
肝臓	1.8	200	21.3
脳	1.4	240	19.9
心臓	0.33	440	8.6
腎臓	0.31	440	8.1
脂肪組織	15	5	4.0
その他	23.16	12	16.5
計	70		100.0

Methodology for evaluation of total energy expenditure

より男性、高齢者より若年者の方が大きいが、これも、除脂肪量や除脂肪の構成比の違いでおおよそ説明がつく[2]。体格のバラツキに伴い、BMRの個人間差は非常に大きく、TEEの個人間差の最大の原因でもある。ただし、一方で、体格が決まれば、ほとんどの場合、±150kcal以内の個人間変動であり、バラツキはそれほど大きくないとも言える[2)6)]。

2) 食事誘発性体熱産生

食後に、主として食物を消化・吸収・運搬するためにみられる熱産生は、たんぱく質を摂取した後に顕著である(摂取したエネルギーの約20～30%)。そのため、長年「特異動的作用(specific dynamic action)」と呼ばれてきた。しかし、糖質や脂質を摂取した場合にも観察される(それぞれ5～10%、～5%)。最近は「食事誘発性熱産生(diet-induced thermogenesis: DITあるいはthermic effect of food (meal) : TEF(TEM))」と呼ばれることが多い。摂取エネルギーのおよそ6～10%程度が食事誘発性体熱産生として消費されると考えられている[7]。

3) 活動時代謝量

身体活動によるエネルギー消費量(活動時代謝量)には、歩行や運動はもちろん、家事や仕事等における動作や姿勢の保持(座位を保つための筋の緊張なども含まれる)など、様々な筋活動を伴う広義の身体活動によるエネルギー消費量が含まれる。

TEEをBMRで割ったPALは、スポーツ選手や重労働従事者でなくても、1.4～2.2前後の広い範囲に分布する。BMRを1400kcal/日、食事誘発性体熱産生をTEEの10%とすると、このPALのバラツキによる活動時代謝量の幅は、およそ350kcal/日～1400kcal/日に相当する。スポーツなどの運動は、せいぜい300kcal/日前後か、多くの場合それ以下であると考えられるので、運動以外の身体活動量(nonexercise activity thermogenesis: NEAT)のバラツキも大きく貢献していると考えられる[8]。

II. エネルギー代謝の測定法

1) 直接法

消費されたエネルギーは、熱となって放散されるため、その熱量を直接測ればよい。代表的な直接法の測定機器であるAtwater-Rosa-Benedict human calorimeterの場合、測定室内の被験者が放射する熱を、室内に張りめぐらされた管を流れる水の温度から測定する。また、室内で発生した水蒸気量から呼気等の水蒸気の気化熱を測定するとともに、体温の変化も考慮して、エネルギー消費量を評価する。このように、装置が大がかりで、活動内容も限定されるため、最近はほとんど使用されていない。

2) 間接法

エネルギーを生み出す際、食物からとりこんだ栄養素が酸素と反応(酸素摂取)し、二酸化炭素を産生する。これらの化学式に基づいて、酸素摂取量と二酸化炭素産生量、および尿中窒素量が正確に得られれば、多くの場合1%程度かそれ以下の誤差で、エネルギー消費量が推定できる。例えば、最もよく利用されるWeir[9]の式は、以下の通りである。

EE (kcal) = 3.941×酸素摂取量 + 1.106×二酸化炭素産生量 − 2.17×尿中窒素排泄量

また、三大栄養素のうち、摂取エネルギーに占めるたんぱく質の割合は比較的安定している。そこで、たんぱく質の占める割合を12.5%と仮定すると、先のWeirの式は以下のようになる。

EE(kcal) =3.9×酸素摂取量+1.1×二酸化炭素産生量

たんぱく質の占める割合が20%を大きく越えるような極端に偏った食事であったり、激しい運動中に限定したりしなければ、尿中窒素排泄量を考慮しないことによる誤差の影響は1%未満であり、呼気分析だけでも十分に正確に測定することができる。

間接法は、直接法と比べて簡便に実施できる上に、ズレの小さい仮定に基づいており、直接法による測定と非常によく一致する。しかも、エネルギー基質の評価が可能である。したがって、しっかりとした呼気分析が行われるのであれば、非常に正確かつ有用な方法である。

III. TEEの評価法

1日あるいはそれ以上の長時間にわたるエネルギー消費量を推定するには、以下のような方法がある。

1)エネルギー代謝測定室

ヒューマンカロリメーターあるいはメタボリックチャン

バーなどとも呼ばれる。人が数時間〜数日生活できる部屋(机やベッド、トイレなど)(図1)と、ガス濃度や流量等の測定機器を備えた設備である。被験者は、マスクのような呼気採取用の特別な機器を装着することなく、室内で自由にあるいは一定の実験計画に従って過ごすことができる。被験者は、滞在中に酸素を消費し二酸化炭素を排出するが、給排気される空気の量を流量計により、給気口と排気口における酸素および二酸化炭素の濃度を濃度分析計により測定する。それらから得られる酸素消費量および二酸化炭素産生量よりエネルギー消費量を推定する「間接法」によるものがほとんどである。測定機器を含む設備全体が十分に管理されれば、既存の設備の中では、数時間以上に及ぶエネルギー消費量を、最も正確に測定することができる。例えば、国立健康・栄養研究所のエネルギー代謝測定室の場合、6時間のアルコール燃焼試験の結果は、エネルギー消費量の真値に対して−0.2±0.5%である。

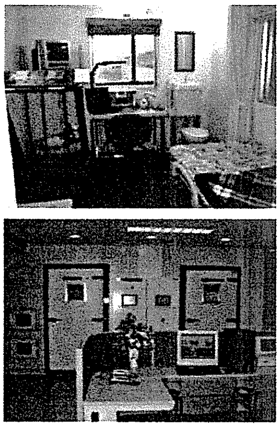

図1 エネルギー代謝測定室の外観(下)と室内(上)

ただし、生活の場所が室内に限定されるため、個人の生活実態を反映した日常のTEEとは異なる。したがって、実験的に再現した特定の条件下(活動内容、食事、その他の室内環境など)におけるエネルギー消費量を測定したり、他の方法の妥当性を検討したりするのに利用される。

2) 二重標識水(Doubly labeled water: DLW)法

DLW法は、水素(O)と酸素(H)の安定同位体を用いてエネルギー消費量を測定する方法で、現時点では、日常生活におけるエネルギー消費量の測定方法のうち最も正確であるとされている[10]。アメリカ/カナダや日本における食事摂取基準のエネルギー必要量は、DLW法により測定されたエネルギー消費量の値を基準に策定されている。

DLW法では原子核が安定し放射性をもたない安定同位体である^{18}Oと^{2}Hを、自然界に存在する比率よりも多く含む水(二重標識水)を、体重あたりで一定の割合で摂取する。この水は4〜8時間程度で体全体の水分にまんべんなくいきわたった後、酸素は水分(尿・汗・呼気中の水蒸気)や呼気ガス中の二酸化炭素として、水素は水分として排出される。そこで、体の水分の一部(尿、唾液など)について、同位体比質量分析計を用いて、^{18}Oと^{16}Oの存在比(^{18}O/^{16}O)と^{2}Hと^{1}Hの存在比(^{2}H/^{1}H)を測定すると、対数で示したそれらの排出率は、図2のように減少する。ここで、^{18}Oの排出率が^{2}Hの排出率より大きく、その差が二酸化炭素の産生量と推測できる。摂取した食物の基質構成比等から推定した呼吸商を用いて酸素摂取量を求め、エネルギー消費量を算出する。

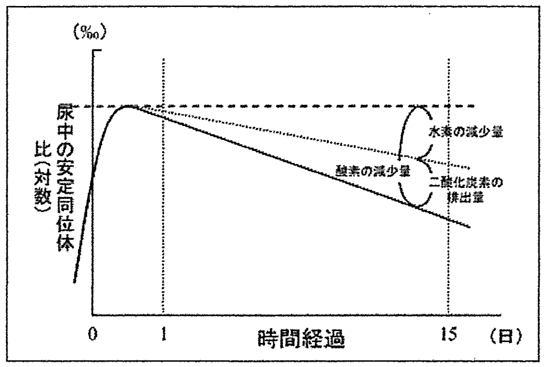

図2 DLW投与後における尿中の安定同位体比の変化

DLW法では、測定される対象者は二重標識水を摂取し、尿や唾液などのサンプルを採るのみで、活動の制約がまったくないため、乳幼児や妊産婦、高齢者など幅広い対象への適用が可能である。一方で、DLW法は、測定期間中の体水分量が一定である、^{18}Oと^{2}Hが水分と二酸化炭素としてのみ体外に排出されるなど、いくつかの前提条件のもとに成りたっている。また、^{18}Oと^{2}Hを投与後、体内での^{18}O/^{16}Oと^{2}H/^{1}Hが十分に低下した時点まで(1〜2週間)の平均のエネルギー消費量を測定する方法であり、短期間のエネルギー消費量を測定するには適さない。^{18}Oの価格が高く、質量比分析計を用いた分析が簡単ではないことから、多数の対象の測定や保健指導等の現場での測定にはそぐわない。TEEの推定精度は、エネルギー代謝室を基準とした場合、確度・精度ともに一般に±5%程度である[10]。

3) 心拍数法

心拍数は、特に中〜高強度の活動において、エネルギー

消費量と正の相関がみられる。そこで、小型の心拍計モニターを使って1日以上にわたって心拍数を測定し、あらかじめ個人別に作成しておいたエネルギー消費量と心拍数との関係式を用いて1日のエネルギー消費量を推定することができる。しかし、日常生活の大部分を占める低強度の活動時においては、エネルギー消費量と心拍数の相関はそれほど強くないため、推定誤差が生じる。また、常に電極を装着し小型のモニターを腰部のベルトなどに携帯することによる不快感や、活動を多少制限する可能性があるという問題もある。分析にもかなりの手間を要する。

4) 加速度計法

歩数あるいは加速度の大きさはエネルギー消費量と正の相関があることを利用して、エネルギー消費量を推定する方法である。一般に腰部に装着し、その多くは数十gなので、不快感は少ない。歩数計の一部および活動量計の多くは上下方向だけ(1次元)の加速度計であるが、3次元の加速度計もある。ただし、比較的低強度の活動をはじめ、重い物を持ってじっと立っている場合、坂道を昇り降りする場合など、加速度の大きさや加速度の振動の速さは、必ずしもエネルギー消費量と対応しないことがある。そのため、活動量を相対的に評価するには有効な手段となるが、一般に1日のエネルギー消費量を過小評価する傾向にある[11)~13)]。また、加速度計の種類によって推定の方法、ひいては推定精度に大きな違いがある。そのため、使用する際には、どのような活動をどの程度正確にとらえることができるのか、事前に確認する必要がある。

5) 生活活動記録法

活動内容を本人または観察者が記録し、それぞれの活動時のエネルギー消費量を、メッツ値[14)]などを用いて推定し、それらを加算することによって、長時間におけるエネルギー消費量を推定する方法である。生活内容に関する情報さえあれば利用できることから、エネルギー消費量・必要量の推定などに、幅広く利用されてきた。ただし、一般に集団の平均値には大きな誤差はないものの、個人における推定誤差はかなり大きいことに留意する必要がある[15)16)]。

IV. エネルギー必要量の考え方

エネルギー必要量は、“エネルギー消費量”から得られる。子ども・妊婦・授乳婦の場合は、更に成長や授乳などに要する付加量が加わる。エネルギー摂取量でないのは、以下の2つの理由による。

・健康な状態であれば、消費した分だけのエネルギーを摂取して、体重を維持する必要があるため

・エネルギー摂取量は、一般に過小評価されるため[17)18)]

「日本人の食事摂取基準(2010年版)」[3)]では、推定エネルギー必要量(EER)とは、「当該年齢、性別、身長、体重、および健康な状態を損なわない身体活動量を有する人において、エネルギー出納(成人の場合、エネルギー摂取量-エネルギー消費量)がゼロ(0)となる確率が最も高くなると推定される、習慣的なエネルギー摂取量の1日当たりの平均値」と定義される。他の栄養素に適用される摂取基準とは異なり、それより少なくても多くてもエネルギー収支が適正である確率は同程度に低下する。DLW法を用いた研究結果を踏まえて、システマティックレビューに基づき決定されている。

推定エネルギー必要量は、BMRにPALを乗じて求める。

EER = BMR × PAL

2010年版の推定エネルギー必要量は、特に運動をしていない人でも、座る、移動で歩く、家事や余暇などの日常における身体活動だけで、BMRの1.6~1.9倍程度のエネルギーを消費していることを意味している。欧米で得られたDLW法の結果をみても、標準的なPALの値はおよそ1.75程度である[4)]。

尚、成人における基礎代謝基準値は20.7kcal/kg/日(50歳以上の女性)~24.0kcal/kg/日(20歳代の男性)である。これに1.75をかけて得られる体重当たりのTEE(kcal/kg/日)は40kcal/kg/日前後、「低い」の代表値である1.5をかけても31~36kcal/kg/日程度となる。これらの値は、「日本糖尿病学会編　糖尿病治療ガイド2008-2009」に示されている値と比べると、かなり大きい。

V. BMRの推定法

BMRは、正確に測ることが可能であれば、個人毎に実測するのが望ましい。しかし、体格でおおよそ決定される

表2 「日本人の食事摂取基準（2010年度版）」における基礎代謝基準値と、基準体重における基礎代謝量

性別	男性			女性		
年齢	基礎代謝基準値 (kcal/kg体重/日)	基準体重 (kg)	基礎代謝量 (kcal/日)	基礎代謝基準値 (kcal/kg体重/日)	基準体重 (kg)	基礎代謝量 (kcal/日)
1～2(歳)	61.0	11.7	710	59.7	11.0	660
3～5(歳)	54.8	16.2	890	52.2	16.2	850
6～7(歳)	44.3	22.0	980	41.9	22.0	920
8～9(歳)	40.8	27.5	1,120	38.3	27.2	1,040
10～11(歳)	37.4	35.5	1,330	34.8	34.5	1,200
12～14(歳)	31.0	48.0	1,490	29.6	46.0	1,360
15～17(歳)	27.0	58.4	1,580	25.3	50.6	1,280
18～29(歳)	24.0	63.0	1,510	22.1	50.6	1,120
30～49(歳)	22.3	68.5	1,530	21.7	53.0	1,150
50～69(歳)	21.5	65.0	1,400	20.7	53.6	1,110
70 以上(歳)	21.5	59.7	1,280	20.7	49.0	1,010

ので、体重などを用いた推定式が様々な対象について作成されている。「日本人の食事摂取基準(2010年版)」[3]においては、BMRを推定するために、性・年齢別に体重に乗じる係数(基礎代謝基準値）が示されている(表2)。2005年版とほぼ同様の値が採用されているが、18～29歳の女性における基礎代謝基準値のみ、23.6 kcal/kg/日から22.1kcal/kg/日に変更された。

基礎代謝基準値、ハリス・ベネディクトの式[19]、および国立健康・栄養研究所から発表された新たな推定式[6]の3つについて、健常な成人男女を対象に、性・年齢階級別に推定誤差をまとめたのが、図3である。基礎代謝基準値は、全体にやや高めではあるものの、推定誤差の平均値は、多くの性・年齢階級で50kcal/日前後である。ただし、推定誤差の標準偏差は、3つの推定式の中で最も大きい。すなわち、基礎代謝基準値を用いたBMR推定値は、平均としてはそれほどずれていないものの、個人別にみると推定誤差が大きいことを示している。これは、性・年齢階級別に一定の係数を体重にかけているだけなのに対し、他の2式が、身長や年齢が連続変数として考慮されていることによると考えられる。また、2010年版で基準値が唯一変更された18～29歳女性においては、新たな基準値を用いると、推定値と実測値の平均値がほぼ一致している。

一方、ハリス・ベネディクトの式では、高齢の男性では推定値と実測値が比較的一致しているものの、それ以外の成人の性・年齢階級では過大評価される。18～29歳女性をはじめとして、男女とも若いほどその差が大きい。それに対して、国立健康・栄養研究所の式は、いずれの性・年齢階級においても、推定誤差の平均および標準偏差とも相対的に良好な値が得られている。

尚、基礎代謝基準値を用いた場合、基準体位から外れるほど、推定の誤差が大きくなり、過体重者では過大評価[20]、低体重者は高く推定される。以上で述べたようなBMRの推定誤差は、もしPALが正しく推定できた場合、その分だけ(標準的な成人であれば1.75倍)、TEEの推定誤差として拡大されることとなる。

<脚注>

国立健康・栄養研究所の式[6]は、以下のとおりである。

BMR＝(0.1238＋0.0481×体重(kg)
　＋0.0234×身長（cm）－0.0138×年齢(歳)
　－0.5473×性別*)
　×1000/4.186(性別*　男性：1　女性：2)

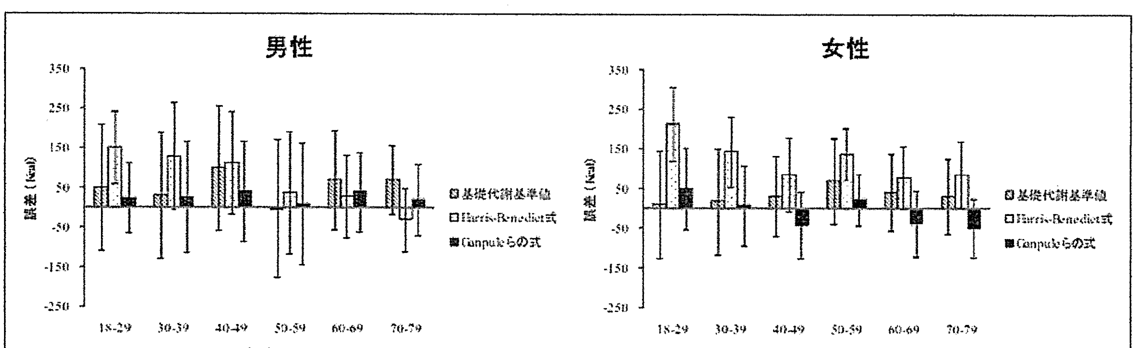

図3 基礎代謝量の各推定式による推定誤差（値は、（推定値－実測値）の平均±標準偏差）

VI. 高齢者

一般に、高齢になるほど身体活動量は減少すると考えられる。「日本人の食事摂取基準(2005年版)」においては、70歳以上における「ふつう」のPALを1.5と低く設定してあった。しかし、2010年版においては、「ふつう」の値が1.7とかなり大きくなり、70歳未満に近い値となった。これは、2005年版策定以降にDLW法を用いた論文で報告された値が全体に大きかったためであり、時代変化というわけではない。

この値は、自立した生活を送っている、比較的元気な高齢者を対象に得られたものであるが、実際は、生活状況により大きな違いがあると考えられる。その点に関するデータはほとんどないが、平均年齢82歳の自宅生活者と施設入居者のPALを比較した報告[21]によると、自宅生活者のPALは平均1.6であったのに対し、施設入居者においては1.4であった。

また、90歳代の男女におけるPALは、それぞれ1.31と1.18であったという報告もある[22]。

VII. 入院患者および自宅療養者

これらの対象者においては、BMRに近い値となるが、活動量が少なくても、以下の点は考慮する必要がある。

・食事誘発性体熱産生がTEEの約10%を占めること
・仰臥位以外の時間や動作量に伴って、エネルギー消費量は大きくなる
(座位は仰臥位より、エネルギー消費量が約10%大きい[23])

これらのことから、ベッド上で仰臥位の時間が長い人でも、食事誘発性体熱産生を考慮して、少なくとも基礎代謝のおよそ10%、多少の動きが加わることを考えると、およそ20%の増加が見込まれる。

また、ヒューマンカロリメーターで健常人あるいは障害者を測定した結果がいくつか報告されているが、一部はPALが1.2強、多くは1.3前後で、健常者において日常生活で想定される下限に近い軽度のプログラムにおいては、約1.4であった[24]。また、ヒューマンカロリメーターを用いた日本人を対象とした研究において、運動等の時間を運動以外の覚醒時の平均で補間すると1.38±0.12というPALの値が得られている[25]。

尚、熱傷をはじめ一部の疾病の場合は、BMRが亢進していることがある[26][27]。それらの対象については、実測するか、BMRの推定値にストレス係数をかけることによって、亢進したBMRを推定する必要がある。ただし、これらの対象者は、身体活動量が非常に少ないため、BMRの亢進があっても、ほとんどの場合、TEEはむしろ低くなる。また、ストレス係数は主に急性期に適用されるべきものであることにも留意する必要がある。

以上の点を踏まえると、ストレス係数が不要である患者におけるエネルギー必要量は、およそ以下のように考えられる。

・ベッドで横になっている時間の多い人：BMRの約1.2倍
・ベッド上で起き上がったりベッド周辺を移動したりする時間が長い人：BMRの約1.3倍
・ベッド近辺に留まらず、自宅内、病棟内を移動できる人：BMRの約1.4倍

もちろん、生活時間の内訳(座位や立位、歩行の時間など)から、おおよその推定も可能である。尚、睡眠時間全体におけるエネルギー消費量はBMRとほぼ等しいことが、欧米人のみならず、日本人においても確認されている[6][25]。

尚、入院患者のBMRの推定にハリス・ベネディクトの式が用いられることが多いが、この式では、先に述べたように、性・年齢階級によって程度は異なるものの、一般健常人においても、全体に高い推定値が得られる。除脂肪量が小さく、栄養状態が低下している入院患者の場合は、更に過大評価の傾向が著しい可能性があると考えられる。

参考文献

1)柏崎浩. エネルギー所要量の歴史と現状. 小林修平編著, 栄養所要量・基準量と食生活ガイドライン. 建帛社、東京、1997、p.61-125.

2) 田中茂穂. 人の基礎代謝量. 実験医学 27 (増刊 肥満・糖尿病の病態を解明するエネルギー代謝の最前線) : 1058-1062、2009.

3) 厚生労働省. 日本人の食事摂取基準 (2010年版) (日本人の食事摂取基準策定検討委員会報告書) 2009.

4) Westerterp KR. Impacts of vigorous and non-vigorous activity on daily energy expenditure. Proc Nutr Soc 62: 645-650, 2003.

5) Elia M. Organ and tissue contribution to metabolic rate. Edited by Kinney JM and Tucker HN. Energy Metabolism. Tissue Determinants and Cellular Corrolaries. Raven Press, New York, 1992, p.61-77.

6) Ganpule AA, Tanaka S, Ishikawa-Takata K, et al. Interindividual variability in sleeping metabolic rate in Japanese subjects. Eur J Clin Nutr 61: 1256-1261, 2007.

7) Van Zant RS. Influence of diet and exercise on energy expenditure--a review. Int J Sport Nutr 2: 1-19, 1992.

8) 田中茂穂. 日常生活における生活活動評価の重要性. 日本公衛誌 55: 474-477, 2008.

9) Weir JBdV. New methods for calculating metabolic rate with special reference to protein metabolism. J Physiol 109: 1-9, 1949.

10) Speakman JR. The history and theory of the doubly labeled water technique. Am J Clin Nutr 68: 932S-938S, 1998.

11) 田中茂穂. 間接熱量測定法による1日のエネルギー消費量の評価. 体力科学 55: 527-532, 2006.

12) 田中茂穂. 身体活動レベル(PAL)とエネルギー必要量. 臨床スポーツ医学 24: 847-853, 2007.

13) Plasqui G, Westerterp KR. Physical activity assessment with accelerometers: an evaluation against doubly labeled water. Obesity (Silver Spring) 15: 2371-2379, 2007.

14) Ainsworth BE, Haskell WL, Whitt MC, et al. Compendium of Physical Activities: An update of activity codes and MET intensities. Med Sci Sports Exerc 32: S498-S516, 2000.

15) 山村千晶、田中茂穂、柏崎浩. 身体活動量に関する質問票の妥当性について. 栄養学雑誌 60: 265-276, 2002.

16) Neilsen HK Neilson HK, Robson PJ, Friedenreich CM, et al. Estimating activity energy expenditure: how valid are physical activity questionnaires? Am J Clin Nutr 87: 279 -291, 2008.

17) Livingstone MB, Black AE. Markers of the validity of reported energy intake. J Nutr 133: 895S-920S, 2003.

18) Okubo H. Sasaki S, Rafamantanantsoa HH, et al. Validation of self-reported energy intake by a self-administered diet histoty questionnaire using the doubly labeled water method in 140 Japanese adults. Eur J Clin Nutr 62: 1343-1350, 2008.

19) Harris JA, Benedict FG. A biometric study of basal metabolism in man. Carnegie Institute of Washington, Washington DC, 1919.

20) Tanaka S, Ohkawara K, Ishikawa-Takata K, et al. Accuracy of predictive equations for basal metabolic rate and contribution of abdominal fat distribution to basal metabolic rate in obese Japanese people. Anti-Aging Med 5: 17-21, 2008.

21) Fuller NJ, Sawyer MB, Coward WA, et al. Components of total energy expenditure in free-living elderly men (over 75 years of age) : measurement, predictability and relationship to quality-of-life indices. Br J Nutr 75: 161-173, 1996.

22) Rothenberg EM, Bosaeus IG, Westerterp KR, et al. Resting energy expenditure, activity energy expenditure and total energy expenditure at age 91-96 years. Br J Nutr 84: 319-324, 2000.

23) 沼尻幸吉. 活動のエネルギー代謝. 増補第2版. 労働科学研究所出版部, 東京, 1979.

24) Black AE, Coward WA, Cole TJ, et al. Human energy expenditure in affluent societies: an analysis of 574 doubly-labelled water measurements. Eur J Clin Nutr 50: 72-92, 1996.

25) 田中茂穂、田中千晶、二見順、ほか. ヒューマンカロリメーターを用いて測定した座位中心の生活における1日あたりのエネルギー消費量. 日本栄養・食糧学会誌 56: 291-296, 2003.

26) Gibney ER. Energy expenditure in disease: time to revisit? Proc Nutr Soc 59: 199-207, 2000.

27) Kulstad R, Schoeller DA. The energetics of wasting diseases. Curr Opin Clin Nutr Metab Care. 10: 488-493, 2007.

Journal of
PHYSIOLOGICAL
ANTHROPOLOGY

Daily Physical Activity in Japanese Preschool Children Evaluated by Triaxial Accelerometry: The Relationship between Period of Engagement in Moderate-to-Vigorous Physical Activity and Daily Step Counts

Chiaki Tanaka[1] and Shigeho Tanaka[2]

1) *Division of Integrated Sciences, J. F. Oberlin University*
2) *Project for Energy Metabolism, Health Promotion and Exercise Program, National Institute of Health and Nutrition*

Abstract The purpose of the present study was to evaluate moderate-to-vigorous physical activity using triaxial accelerometry in Japanese preschool children. The relationship between daily step counts as a convenient measure of physical activity and minutes of engagement in moderate-to-vigorous physical activity was also examined. Physical activity was assessed using a triaxial accelerometer (ActivTracer, GMS) and daily steps using a uniaxial accelerometer for 6 consecutive days, including weekdays and weekend days, in 157 four- to six-year-old Japanese children attending kindergarten or nursery school. Using triaxial and uniaxial accelerometers, nonlocomotive activities and step counts for young children can be evaluated, respectively. Average daily moderate-to-vigorous physical activity (physical activity ratio ≥3) and step counts were 102 (±32) min/day and 13,037 (±2,846) steps/day, respectively. A strong and significant correlation was observed between minutes of moderate-to-vigorous physical activity and step counts ($r=0.832$, $p<0.001$). The daily step counts corresponding to 60 min, 100 min, and 120 min of moderate-to-vigorous physical activity were 9,934, 12,893, and 14,373 steps/day, respectively. The correlation coefficient between minutes of higher intensity activities (physical activity ratio ≥4) and step counts was slightly lower ($r=0.604$, $p<0.001$). The daily step count corresponding to 30 min of the higher intensity activities was 14,768 steps/day. These results suggest that approximately 13,000 steps/day are required for preschool children to engage in more than 100 min of moderate-to-vigorous physical activity. *J Physiol Anthropol 28(6): 283–288, 2009* http://www.jstage.jst.go.jp/browse/jpa2
[DOI: 10.2114/jpa2.28.283]

Keywords: physical activity, accelerometry, preschool children, pedometer, total steps

Introduction

Physical activity (PA) guidelines for young people have been available since the 1980s. Currently, most of the PA guidelines recommend at least 60 min per day of at least moderate-intensity PA (Biddle et al., 1998; National Association for Sport and Physical Education, 2002, 2004; Strong et al., 2005). Therefore, an accurate evaluation of daily PA in young children is important. The questionnaire (e.g., activity diary) and accelerometer methods are relatively noninvasive. Recently, Wareham et al. (2005) and Blair and Haskell (2006) have argued that objective measurements are necessary to accurately evaluate PA. Self-reported measures for PA are particularly difficult in young children, because the questionnaire is subjective and the measures for PA depend on the observer. An objective measurement approach using an accelerometer avoids these limitations, and an accelerometer can be used to predict energy expenditure and to classify levels of PA (Chen and Bassett, 2005; Freedson et al., 2005; Matthews, 2005; Treuth et al., 2004).

Accelerometers may be particularly useful for measuring physical activity in preschool-aged children, because they are not usually engaged in prolonged exercise. Validation studies of accelerometers have been performed in preschool children (Pate et al., 2006; Pfeiffer et al., 2006; Reilly et al., 2003; Sirard et al., 2005; Tanaka et al., 2007a, b). Moreover, Eston et al. (1998) showed that three-dimensional accelerometers may provide a better evaluation of children's free-play activities than uniaxial accelerometers. One of the reasons is that movement within the anteroposterior plane as measured with triaxial accelerometry is the main component of physical activity of typical children (mean age 9.2 +/− 0.8 yr). Moreover, Oliver et al. (2007) pointed out that preschoolers participate in activities that require less vertical movement and more omnidirectional movement. Thus, triaxial accelerometers may capture total body movement better than uniaxial devices

(Chen and Bassett, 2005; Matthews, 2005). However, little data on PA intensity, especially in preschool-aged children in free-living conditions, has been obtained using triaxial accelerometers (see reviews by Oliver et al. (2007) and Hinkley et al. (2008)). In addition, a recent study of ours has shown that discrimination between ambulation and play in preschool children (e.g., ball tossing) using a triaxial accelerometer (ActivTracer, GMS) contributes to better evaluation of PA intensity (Tanaka et al., 2007a). Similar results were reported in adults (Midorikawa et al., 2007). These studies suggest that relationships between PA intensity and acceleration counts are different between locomotion and the other types of PA, and that previous studies (even with a triaxial accelerometer) did not assess types of PA other than locomotion. However, the ActivTracer is expensive (about $2,000 (USD)) and does not have specific software to calculate energy expenditure for evaluating PA. Thus, for research studies with large sample sizes, more convenient devices such as pedometers are more useful than the triaxial accelerometer, although pedometers cannot evaluate levels of PA.

Two recommendations for the average daily number of steps have been suggested for elementary school-aged children (Tudor-Locke et al., 2004; Vincent and Pangrazi, 2002). Vincent and Pangrazi (2002) recommended 13,000 steps/day for boys and 11,000 steps/day for girls. Tudor-Locke et al. (2004, 2008) recommended 15,000 and 12,000 steps/day, respectively. Eisenmann et al. (2007) examined the utility of these recommendations in predicting childhood adiposity. They found that the likelihood of being classified as overweight was greater for subjects who did not meet the recommendation for steps per day than for those who did meet it. Locomotion is one of the important parts of PA in free-living conditions and daily step counts have been used as an index of PA in many studies. However, data on daily PA and total steps in representative samples of preschool-aged children using the accelerometer remain insufficient, particularly for Japanese (Cardon and De Bourdeaudhuij, 2007; Fisher et al., 2005; Jackson et al., 2003; Montgomery et al., 2004; Pate et al., 2004), and data on the relationship between total steps and minutes of engagement in moderate-to-vigorous physical activity (MVPA), except for data reported by Cardon and De Bourdeaudhuij (2007), are lacking. Cardon and De Bourdeaudhuij (2007) found a relatively strong correlation ($r=0.73$) between daily step counts and minutes of engagement in MVPA using a uniaxial accelerometer (MTI Actigraph) in 4- and 5-year-old children. However, accelerometers with a single regression equation based on locomotive activity underestimate the energy expenditure of nonlocomotive activities in adults (Matthews, 2005) and young children (Tanaka et al., 2007a). Unlike adults, children engage in types of PA other than locomotion (Oliver et al., 2007). Therefore, the present study used a vertical/horizontal counts ratio as a classification criterion and to discriminate between different types of medium-intensity activities including walking and nonlocomotive activities (Tanaka et al., 2007a).

The purposes of this study were 1) to describe the patterns of PA classified according to intensity using a triaxial accelerometer (ActivTracer, GMS), which can discriminate locomotive from nonlocomotive activities, and 2) to measure total daily number of steps using uniaxial accelerometry (Lifecorder EX, Suzuken) in Japanese preschool children. We also examined the relationship of daily step counts (a simple method for measuring PA) to minutes of engagement in MVPA.

Methods

Subjects

The subjects were 212 four- to six-year-old Japanese preschool children (85 girls and 127 boys; mean age 5.8 ± 0.6 years, range 4.5–6.8 years), living in the Tokyo metropolitan area and attending kindergarten or nursery school. All of the subjects reported being in good health, without any anamnesis of conditions affecting energy expenditure, such as abnormal thyroid gland function. Informed consent was obtained from a parent, and the Ethical Committee of J. F. Oberlin University approved the study protocol.

Measurement items and methods

Body height and weight were measured to the nearest 0.1 cm and 0.1 kg, respectively. Habitual PA was measured using a triaxial accelerometer (ActivTracer, GMS, Tokyo) and a uniaxial accelerometer (Lifecorder EX, Suzuken, Nagoya). The subjects wore a 57-gram ActivTracer and a 60-gram Lifecorder EX on the left side of the waist, as previously described (Tanaka et al., 2007a, b). The ActivTracer was set to record in 1-min epochs; the Lifecorder EX was set to measure exercise intensity in 4-sec epochs and step counts in 1-min epochs. PA was monitored continuously for 6 days (generally, 4 weekdays plus 2 weekend days). Subjects were requested to wear these devices except during unavoidable circumstances, such as dressing and bathing. The times that the subjects did not wear the equipment and sleeping times were recorded by their parents. The Lifecorder EX records a signal of 0.5 or 1 to 9 every 4 seconds while being worn, even if the subjects are asleep. When no signal was detected for more than one hour by the Lifecorder, the period was regarded as nonwearing time for both the ActivTracer and Lifecorder. We excluded days during which more than 2 hours of non-wearing time had accrued, not counting time allowed for the above-mentioned unavoidable reasons, and days during which subjects were absent from kindergarten or nursery school. Subjects with at least two weekdays and at least one weekend were used in the analyses. As a result, PA was measured successfully in 157 of 212 children (74%).

Synthetic activity counts were recorded every 1 min by the ActivTracer, and PAR (physical activity ratio), a multiple of basal metabolic rate, was estimated as previously described (Tanaka et al., 2007a). When the synthetic activity counts were in the range corresponding to medium-intensity activities (between 130 and 600 mG), classification criteria using the vertical/horizontal counts ratio (as previously described) were used to discriminate different types of medium-intensity activities, because the PAR for some medium-intensity activities (i.e., non-locomotive activities) are underestimated (Tanaka et al., 2007a): The vertical/horizontal ratio for 1) walking is ≥1.19 and for 2) nonlocomotive activities, <1.19.

Furthermore, daily step counts were evaluated using a Lifecorder EX. With this device, if the second step is not recognized within 1.5 seconds, the first step is not counted.

Analyses

Average number of weekday and weekend minutes spent in MVPA (PAR ≥3), PAR ≥4, and medium-intensity activities, number of steps, and physical activity level (PAL; total energy expenditure/basal metabolic rate) were calculated for each individual, and then the average weekly values were calculated by weighting for 5 weekdays and 2 weekend days. The relationship between the two variables was evaluated by Pearson's correlation and a linear regression model. A Student's t-test was carried out to assess the influence of gender. All results are shown as the mean±standard deviation (SD). Statistical analyses were performed with SPSS version 15.0J for Windows (SPSS Inc, Japan, Tokyo). All statistical tests were regarded as significant when the p-values were less than 0.05.

Results

The physical characteristics of the subjects are shown in Table 1. Most of the subjects in the present study were of normal weight. The numbers of overweight girls and boys based on body mass index (Cole et al., 2000) were 2 and 5, respectively. One girl was obese. Morphological variables did not show a gender difference.

Table 1 Physical characteristics of subjects

Variable	All subjects (n=157) Mean±SD	Girls (n=69) Mean±SD	Boys (n=88) Mean±SD
Age (yr)	5.9±0.5	5.9±0.5	5.9±0.5
Height (cm)	112.0±5.6	112.3±4.7	111.8±6.2
Weight (kg)	19.0±2.8	18.9±2.6	19.0±3.0
Body mass index (kg/m²)	15.1±1.3	15.0±1.4	15.1±1.2

Times in MVPA and PAR ≥4, step counts, and PAL are shown in Table 2. All values for boys were significantly higher than those for girls. The daily step counts of subjects in the present study were normal based on the step count cutoff values suggested by Tudor-Locke et al. (2008).

Figures 1 and 2 show the relationship between MVPA minutes or minutes of PAR ≥4 and step counts. Strong significant correlations were observed between MVPA minutes and step counts (r=0.833, $p<0.001$). The daily step counts corresponding to 60 min, 100 min, and 120 min of MVPA were 9,934, 12,893, and 14,373 steps, respectively, and 92.4%,

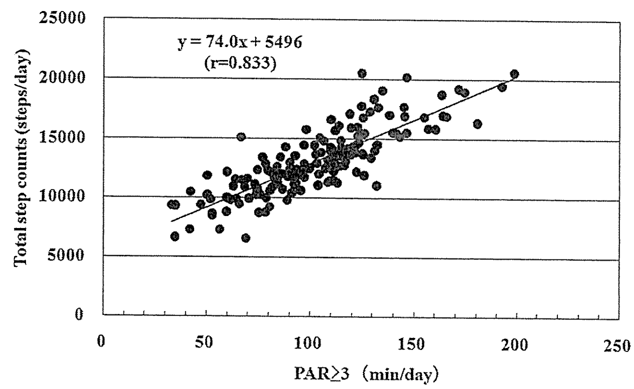

Fig. 1 Relationship between minutes engaged in moderate-to-vigorous physical activity (PAR ≥3) and daily step counts.

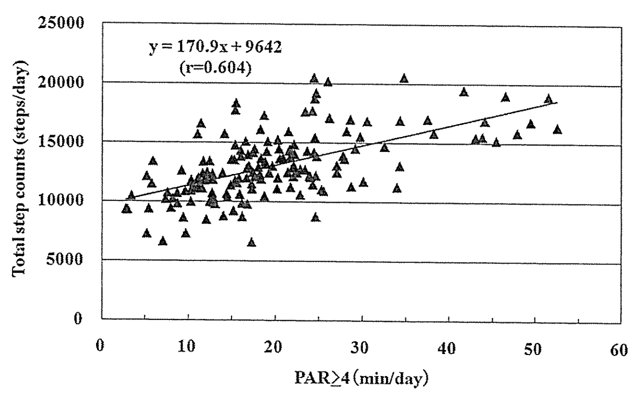

Fig. 2 Relationship between minutes engaged in PAR ≥4 activity and daily step counts.

Table 2 Characteristics of daily physical activity

Activity	All subjects (n=157) Mean±SD	Girls (n=69) Mean±SD	Boys (n=88) Mean±SD
Time in MVPA (min/day)	102.0±32.0	88.8±28.9	112.3±30.7*
Time in PAR ≥4 (min/day)	19.9±10.1	16.4±9.0	22.6±10.1*
Step counts (counts/day)	13037±2846	12255±2823	13650±2726*
PAL	1.54±0.08	1.51±0.07	1.55±0.08*

MVPA: moderate-to-vigorous physical activity, PAR: physical activity ratio, PAL: physical activity level, *: girls vs boys $p<0.05$.

51.6%, and 27.4% of the children attained these levels of MVPA, respectively. Furthermore, a significant correlation was also observed between minutes of PAR ≥4 and step counts (r=0.604, $p<0.001$). The daily step count corresponding to 30 min of PAR ≥4 activity (engaged in by 12.7% of the children) was 14,768 steps. When synthetic activity counts corresponding to medium-intensity activity (between 130 and 600 mG) were obtained, the amount of time spent in walking-type and nonlocomotive-type activities was 74±41 min/day and 167±47 min/day, respectively.

Discussion

Comparison with previous studies

This study evaluated MVPA using triaxial accelerometry in preschool-aged Japanese children. The association between daily step counts measured by uniaxial accelerometry and minutes of engagement in MVPA was also examined, as the uniaxial accelerometer is a more conventional method for measuring PA. Tanaka et al. (2007a) defined an MVPA cutoff point of PAR ≥3 for preschool-aged children; the average value of PAR for normal walking is 2.6. Therefore, in the present study, MVPA would have consisted of activities such as brisk walking, ball tossing, or more vigorous activities.

The current international guidelines recommend at least 60 min or more per day of MVPA for children's health maintenance (Biddle et al., 1998; National Association for Sport and Physical Education, 2002, 2004; Strong et al., 2005). In the present study, 92.4% of the children spent ≥60 min/day in MVPA, and 51.6% of the children spent ≥100 min/day in MVPA. The average amount of MVPA was 102±32 min/day. To our knowledge, this is the first report to examine Japanese children's PA level using a triaxial accelerometer. In a previous study (Montgomery et al., 2004), direct observation of 2.6- to 6.9-year-old children showed that they spent most of their time engaged in sedentary activities (girls: 79%, boys: 73%) and only small amounts of time in MVPA (3% and 4%, respectively) as measured by a CSA/MTI uniaxial accelerometer. Reilly et al. (2004) also observed that the median time spent in MVPA was only 4% at 5 years of age as measured by a CSA/MTI uniaxial accelerometer. Alhassan et al. (2007), using an ActiGraph uniaxial accelerometer, showed that the average total daily time spent in MVPA at age 3.6±0.5 years was 2.0±1.6% in the intervention group and 1.4±0.9% in the control group. However, the results of the present study coincided closely with results in other previous studies of youth activity level measured by heart-rate monitor or accelerometer (Andersen et al., 2006; Epstein et al., 2001). Andersen et al. (2006), using an ActiGraph uniaxial accelerometer, showed that the average time spent at levels above 4 km/h at age 9 years was 116 min and at 15 years 88 min. On the other hand, Epstein et al. (2001), using a heart rate monitor, found that youths aged 3 to 17 years engaged in MVPA for 60–120 min. However, it should be noted that the present data were recorded at 1-min epochs, which may not be sensitive enough to pick up short bursts of vigorous activity (Nilsson et al., 2002). As Freedson et al. (2005) pointed out, a major and as yet unresolved problem of comparing studies is the lack of a consensus on how the activity intensity cutoff points are defined.

Our previous study showed that linear and nonlinear regression equations using vertical acceleration counts overestimated PAR for very low-intensity activities and underestimated PAR for nonlocomotive activities (such as ball tossing and stair climbing) more than the other models for preschool-aged children (Tanaka et al., 2007a). However, all models underestimated PAR while ball tossing and stair climbing to the same degree. Therefore, an additional analysis was applied in the present study to distinguish these activities from walking. The results show that the present subjects were engaged in walking-type activities for 74±41 min/day and in nonlocomotive-type activities for 167±47 min/day. Thus, adjustment of the values predicted by the regression equations using the vertical/horizontal counts ratio improved the underestimation of PAR for nonlocomotive activities such as ball tossing. The obtained average percentage difference was improved from −32.1±18.9% to −4.7±15.5%. The results also suggest that the previous algorithms for evaluation of PA intensity using accelerometers may lead to erroneous estimations of PA intensities. In addition, some of the previous studies (Montgomery et al., 2004, Reilly et al., 2004) were based on cutoff values applied to accelerometer output that was validated against direct observation in 3- to 5-year-olds (Reilly et al., 2003; Sirard et al., 2005). Therefore, the difference in daily time spent in MVPA between our data and previous studies might be explained by different cutoff points and algorithms.

Relationship between period of engagement in moderate-to-vigorous physical activity and daily step counts

The average daily step count in the present study was 13,037±2,846 steps/day in 4- to 6-year-old children. On the other hand, Cardon and De Bourdeaudhuij (2007) reported that the average daily step count in 4- to 5-year-olds was 9,980±2,605 steps/day, and concluded that daily step counts in preschool-aged children were low. There are two recommendations regarding the number of steps per day for elementary school children (Tudor-Locke et al., 2004; Vincent and Pangrazi, 2002). Vincent and Pangrazi (2002) recommended 11,000 steps/day for girls and 13,000 steps/day for boys. Tudor-Locke et al. (2004) recommended 12,000 and 15,000 steps/day, respectively. The average values of the present study were similar to all recommended values, except the value for boys recommended by Tudor-Locke. Nakae et al. (2008) recently reported that a spring-levered pedometer underestimates step counts at the slow and normal paces of young children by more than 20%, whereas piezo-electric pedometers are much more accurate. Cardon and De Bourdeaudhuij (2007) used a spring-levered pedometer (Yamax Digiwalker) while we used a piezo-electric pedometer

(Lifecorder EX), which may be the main reason for the considerably different average step counts. Thus, the average step counts for preschool-aged children might be higher than that measured by the previous study (Cardon and De Bourdeaudhuij, 2007).

Locomotion comprises one of the important parts of physical activity in free-living conditions, and daily step counts have been used as an index of physical activity in many studies. However, the relationship between daily step counts and MVPA engagement time has not been examined except by Cardon and De Bourdeaudhuij (2007). In the present study, a strong and significant correlation was observed between minutes of MVPA and step counts ($r=0.833$, $p<0.001$). The daily step counts in 60 min, 100 min, and 120 min of moderate-to-vigorous physical activity were 9,934, 12,893, and 14,373 steps, respectively, and 92.4%, 51.6%, and 27.4% of the children attained these step count levels, respectively. The relationship between minutes of MVPA and step counts was in agreement with the results reported by Cardon and De Bourdeaudhuij (2007) ($r=0.73$, $p<0.001$). However, only 8% of their subjects reached the daily step count level corresponding to 60 min of MVPA per day. Thus, the percentage of children achieving this level was higher in the present study than in their study. Though differences in categorization of moderate-intensity activities might influence the results, both studies categorized, as similar, activities with the same intensity level; namely, they also categorized brisk walking as a moderate-intensity activity. The present study categorized brisk walking as a moderate-intensity activity because our previous study revealed that the PAR for normal-speed walking in 6-year-olds was 2.60 ± 0.49 (Tanaka et al., 2007a). However, other differences in cutoff points might help explain the disparate results.

A significant correlation was also observed between minutes of PAR $\geq$4 and step counts ($r=0.604$, $p<0.001$), and 12.7% of the children engaged in 30 min or more of PAR $\geq$4 activity. The correlation coefficient was slightly lower than that for PAR $\geq$3. Because the PAR for normal walking is 2.60 ± 0.49 (Tanaka et al., 2007a), it is estimated that PAR $\geq$4 activities such as very brisk walking and running comprised a small percentage of overall locomotion, which may be the main reason for the weaker correlation. Thus, total number of steps may be a good index for moderate-intensity PA, though not for relatively high-intensity PA.

The estimated average time engaged in locomotion was 106 min, as calculated by average daily step counts in the present study (13,037 steps) and by the average step rate (122.7 steps/min) in our calibration study (Tanaka et al., 2007b). However, the percentage of time in nonlocomotive type activities was much larger than that spent in walking type activities, in the range of synthetic activity counts corresponding to medium-intensity activity. In addition, only brisk (but not normal) walking and running are included in MVPA, judging from the average PAR for normal walking in the calibration study (Tanaka et al., 2007a). Therefore, it should be noted that less than half of the 106 min was spent in MVPA in the present study. Nevertheless, the average amount of time engaged in MVPA as measured by triaxial accelerometry was almost 100 min and was strongly correlated with total daily number of steps. These results indicate that young children who engage in a substantial amount of MVPA have high daily step counts, even though prolonged locomotion does not comprise a large part of total MVPA.

In conclusion, this study suggests that daily step counts give valid information on daily physical activity for preschool-aged children. These children need to take 12,893 steps/day to attain the recommended 100 min/day of MVPA or 14,758 steps/day to attain 30 min/day of PAR $\geq$4 activity.

Acknowledgements The authors would like to thank the subjects, their parents, and the staff of the participating kindergartens and nursery schools for their cooperation in this study. We also wish to thank Mr. Sho Izumida for his help with the experiments. This work was supported by a Grant-in-Aid for Young Scientists (B) of the Japan Society for the Promotion of Science (to C. Tanaka) and by a Sports Medicine and Science Research grant from the Japan Sports Association (to S. Tanaka).

References

Alhassan S, Sirard JR, Robinson TN (2007) The effects of increasing outdoor play time on physical activity in Latino preschool children. Int J Pediatr Obes 2: 153–158

Andersen LB, Harro M, Sardinha LB, Froberg K, Ekelund U, Brage S, Anderssen SA (2006) Physical activity and clustered cardiovascular risk in children: a cross-sectional study (The European Youth Heart Study). Lancet 368: 299–304

Biddle S, Sallis JF, Cavill N (1998) Young and active? Young people and health-enhancing physical activity—evidence and implications. United Kingdom: Health Education Authority, London, 1–176

Blair SN, Haskell WL (2006) Objectively measured physical activity and mortality in older adults. JAMA 296: 216–218

Cardon G, De Bourdeaudhuij I (2007) Comparison of pedometer and accelerometer measures of physical activity in preschool children. Pediatr Exerc Sci 19: 205–214

Chen KY, Bassett DR Jr (2005) The technology of accelerometry-based activity monitors: current and future. Med Sci Sports Exerc 37: S490–S500

Cole TJ, Bellizzi MC, Flegal KM, Dietz WH (2000) Establishing a standard definition for child overweight and obesity worldwide: international survey. BMJ 320: 1240–1243

Eisenmann JC, Laurson KR, Wickel EE, Gentile D, Walsh D (2007) Utility of pedometer step recommendations for predicting overweight in children. Int J Obes 31: 1179–1182

Epstein LH, Paluch RA, Kalakanis LE, Goldfield GS, Cerny FJ, Roemmich JN (2001) How much activity do youth get?

A quantitative review of heart-rate measured activity. Pediatrics 108: E44
Eston RG, Rowlands AV, Ingledew DK (1998) Validity of heart rate, pedometry, and accelerometry for predicting the energy cost of children's activities. J Appl Physiol 84: 362–371
Fisher A, Reilly JJ, Kelly LA, Montgomery C, Williamson A, Paton JY, Grant S (2005) Fundamental movement skills and habitual physical activity in young children. Med Sci Sports Exerc 37: 684–688
Freedson P, Pober D, Janz KF (2005) Calibration of accelerometer output for children. Med Sci Sports Exerc 37: S523–S530
Hinkley T, Crawford D, Salmon J, Okely AD, Hesketh K (2008) Preschool children and physical activity: a review of correlates. Am J Prev Med 34: 435–441
Jackson DM, Reilly JJ, Kelly LA, Montgomery C, Grant S, Paton JY (2003) Objectively measured physical activity in a representative sample of 3- to 4-year-old children. Obes Res 11: 420–425
Matthews CE (2005) Calibration of accelerometer output for adults. Med Sci Sports Exerc 37: S512–S522
Midorikawa T, Tanaka S, Kaneko K, Koizumi K, Ishikawa-Takata K, Futami J, Tabata I (2007) Evaluation of low-intensity physical activity by triaxial accelerometry. Obesity 15: 3031–3038
Montgomery C, Reilly JJ, Jackson DM, Kelly LA, Slater C, Paton JY, Grant S (2004) Relation between physical activity and energy expenditure in a representative sample of young children. Am J Clin Nutr 80: 591–596
Nakae S, Oshima Y, Ishii K (2008) Accuracy of spring-levered and piezo-electric pedometers in primary school Japanese children. J Physiol Anthropol 27: 233–239
National Association for Sport and Physical Education (2002) Active start: a statement of guidelines for children birth to five years. Reston, VA: Author
National Association for Sport and Physical Education (2004) Physical activity for children: a statement of guidelines. 2nd ed. Reston, VA: Author
Nilsson A, Ekelund U, Yngve A, Sjostrom M (2002) Assessing physical activity among children with accelerometers using different time sampling intervals and placements. Pediatr Exerc Sci 14: 87–96
Oliver M, Schofield GM, Kolt GS (2007) Physical activity in preschoolers: understanding prevalence and measurement issues. Sports Med 37: 1045–1070
Pate RR, Pfeiffer KA, Trost SG, Ziegler P, Dowda M (2004) Physical activity among children attending preschools. Pediatrics 114: 1258–1263
Pate RR, Almeida MJ, McIver KL, Pfeiffer KA, Dowda M (2006) Validation and calibration of an accelerometer in preschool children. Obesity 14: 2000–2006
Pfeiffer KA, McIver KL, Dowda M, Almeida MJ, Pate RR (2006) Validation and calibration of the Actical accelerometer in preschool children. Med Sci Sports Exerc 38: 152–157
Reilly JJ, Coyle J, Kelly L, Burke G, Grant S, Paton JY (2003) An objective method for measurement of sedentary behavior in 3- to 4-year olds. Obes Res 11: 1155–1158
Reilly JJ, Jackson DM, Montgomery C, Kelly LA, Slater C, Grant S, Paton JY (2004) Total energy expenditure and physical activity in young Scottish children: mixed longitudinal study. Lancet 363: 211–212
Sirard JR, Trost SG, Pfeiffer KA, Dowda M, Pate RR (2005) Calibration and evaluation of an objective measure of physical activity in preschool children. J Phys Act Health 3: 345–357
Strong WB, Malina RM, Blimkie CJ, Daniels SR, Dishman RK, Gutin B, Hergenroeder AC, Must A, Nixon PA, Pivarnik JM, Rowland T, Trost S, Trudeau F (2005) Evidence based physical activity for school-age youth. J Pediatr 146: 732–737
Tanaka C, Tanaka S, Kawahara J, Midorikawa T (2007a) Triaxial accelerometry for assessment of physical activity in young children. Obesity 15: 1233–1241
Tanaka C, Tanaka S, Kawahara J, Midorikawa T (2007b) Uniaxial accelerometer for assessing physical activity in 5- to 6-year old children. Jpn J Phys Fitness Sports Med 56: 489–500
Treuth MS, Schmitz K, Catellier DJ, McMurray RG, Murray DM, Almeida MJ, Going S, Norman JE, Pate R (2004) Defining accelerometer thresholds for activity intensities in adolescent girls. Med Sci Sports Exerc 36: 1259–1266
Tudor-Locke C, Pangrazi RP, Corbin CB, Rutherford WJ, Vincent SD, Raustorp A, Tomson LM, Cuddihy TF (2004) BMI-referenced standards for recommended pedometer-determined steps/day in children. Prev Med 38: 857–864
Tudor-Locke C, Hatano Y, Pangrazi RP, Kang M (2008) Revisiting "how many steps are enough?". Med Sci Sports Exerc 40: S537–S543
Vincent SD, Pangrazi RP (2002) An examination of the activity patterns of elementary school children. Pediatr Exerc Sci 14: 432–441
Wareham NJ, van Sluijs EM, Ekelund U (2005) Physical activity and obesity prevention: a review of the current evidence. Proc Nutr Soc 64: 229–247

Received: June 5, 2009
Accepted: September 29, 2009
Correspondence to: Chiaki Tanaka, J. F. Oberlin University, 3758 Tokiwamachi, Machida, Tokyo 194–0294, Japan
Phone: +81–42–797–9145
Fax: +81–42–797–9145
e-mail: c-tanaka@obirin.ac.jp

Gait & Posture xxx (2010) xxx–xxx

Contents lists available at ScienceDirect

Gait & Posture

journal homepage: www.elsevier.com/locate/gaitpost

Classifying household and locomotive activities using a triaxial accelerometer

Yoshitake Oshima [a,*], Kaori Kawaguchi [a], Shigeho Tanaka [b], Kazunori Ohkawara [b], Yuki Hikihara [b,c], Kazuko Ishikawa-Takata [b], Izumi Tabata [b]

[a] Research and Development Department, Omron Healthcare Co., Ltd., 24 Yamanouchi Yamanoshita-cho, Ukyo-ku, Kyoto 615-0084, Japan
[b] Health Promotion and Exercise Program, National Institute of Health and Nutrition, Tokyo, Japan
[c] Faculty of Engineering, Chiba Institute of Technology, Narashino, Japan

ARTICLE INFO

Article history:
Received 14 April 2009
Received in revised form 18 December 2009
Accepted 7 January 2010

Keywords:
Accelerometer
Physical activity
Gravitational acceleration
Posture

ABSTRACT

The purpose of this study was to develop a new algorithm for classifying physical activity into either locomotive or household activities using a triaxial accelerometer. Sixty-six volunteers (31 men and 35 women) participated in this study and were separated randomly into validation and cross-validation groups. All subjects performed 12 physical activities (personal computer work, laundry, dishwashing, moving a small load, vacuuming, slow walking, normal walking, brisk walking, normal walking while carrying a bag, jogging, ascending stairs and descending stairs) while wearing a triaxial accelerometer in a controlled laboratory setting. Each of the three signals from the triaxial accelerometer was passed through a second-order Butterworth high-pass filter to remove the gravitational acceleration component from the signal. The cut-off frequency was set at 0.7 Hz based on frequency analysis of the movements conducted. The ratios of unfiltered to filtered total acceleration (TAU/TAF) and filtered vertical to horizontal acceleration (VAF/HAF) were calculated to determine the cut-off value for classification of household and locomotive activities. When the TAU/TAF discrimination cut-off value derived from the validation group was applied to the cross-validation group, the average percentage of correct discrimination was 98.7%. When the VAF/HAF value similarly derived was applied to the cross-validation group, there was relatively high accuracy but the lowest percentage of correct discrimination was 63.6% (moving a small load). These findings suggest that our new algorithm using the TAU/TAF cut-off value can accurately classify household and locomotive activities.

1. Introduction

The modern lifestyle with reduced physical activity and a dietary intake greater than needed for daily energy expenditure is closely related to an increasing proportion of obese people. Low levels of physical activity are also associated with cardiovascular diseases [1], type 2 diabetes mellitus [2,3], and osteoporosis [4,5]. In order to prevent and control obesity and other diseases, moderate-intensity physical activity is recommended [6–8]. It has been reported that occupational, leisure-time, and household activities are also effective in the prevention of obesity and related diseases [9,10]. In fact, energy expenditure (EE) induced by these activities is much larger than exercise-induced EE when measured throughout the day [11]. In addition, a large inter-individual variation is observed in EE for these activities [10,11]. Therefore, it would be very useful for obesity research to measure both locomotive and household activities accurately.

There are several methods for evaluating short- and long-term physical activities under free-living conditions [12,13]. Accelerometers are currently used by some groups as monitoring tools because they are small, non-invasive, and relatively inexpensive [14]. Although several prediction equations have been developed, a single regression equation based on walking and jogging underestimates the EE of moderate-intensity household activities [15]. In contrast, a single regression equation based on household activity overestimates the EE of sedentary and light activities and underestimates the EE of vigorous activities [15,16]. Therefore, recent studies have attempted to classify physical activity into locomotive and household activities using an accelerometer. Although techniques for correct discrimination have been examined, their validity and usefulness for improving the accuracy of EE prediction have not been sufficiently proven. In addition, household activity comprises some part of total physical activity and non-exercise activity thermogenesis (NEAT). However, most studies have focused on locomotive activities such as walking and jogging, and the degree to which household activity contributes to the total amount (duration and EE) of physical activity under free-living conditions remains unclear.

* Corresponding author. Tel.: +81 75 322 9314; fax: +81 75 322 9328.
E-mail address: yoshitake_oshima@ohq.omron.co.jp (Y. Oshima).

0966-6362/$ – see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.gaitpost.2010.01.005