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Individual variations in steps per day for meeting physical activity guidelines in young adult women

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Title:

Individual variations in steps per day for meeting physical activity guidelines in young adult women

Running head:

Step count versus activity at specific intensities

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Abstract

Cross-sectional studies have found a correlation between the duration or volume of moderate-to-vigorous physical activity (MVPA) and steps per day (STEP), but there is little information on why this relationship varies among individuals. No previous research has established whether STEP can be used to estimate the duration of PA at or above lactate threshold (\geq LT), such as for maintaining cardiorespiratory fitness. This study explored the association among STEP, MVPA indices and \geq LT under free-living conditions. Seventy young adult women measured their PA for 7 days using a validated accelerometer. The mean LT measured by an exercise test was 5.8 ± 1.0 METs. STEP, MVPA, METs \times h and \geq LT were 9324 ± 2677 steps/d, 231.9 ± 101.5 min/w, 16.6 ± 7.4 METs \times h/w and 24.0 ± 22.2 min/w, respectively. Significant correlations were found between STEP and MVPA duration and between STEP and METs \times h/w ($r = 0.81$ and $r = 0.81$); however, approximately 1600 steps/d of the standard error of estimates in the regression equations were found. Multiple stepwise regression analysis revealed that the percentage of total time spent at light-intensity PA (LPA) and MVPA were significant determinants of the percent deviation of STEP from the linear relationships between STEP and MVPA indices. No significant relationship was observed between \geq LT and STEP. The association between STEP and MVPA fluctuated depending on individual daily LPA and MVPA. Thus, consideration of both STEP and the PA at specific intensities are necessary to ensure the PA guidelines are met and the health benefits gained. STEP alone would be not a sufficient indicator for assessing the \geq LT.

Key words: Accelerometer; Aerobic fitness; Exercise intensity; Exercise prescription; Locomotion; Physical activity; Step count

Introduction

A physically active lifestyle and improvements in cardiorespiratory fitness bring numerous health benefits, including a reduced incidence of non-communicable diseases and a reduction in the risk of overall mortality (Haskell et al. 2007; Ishikawa-Takata and Tabata 2007; Kodama et al. 2009; Lee et al. 2012). In the context of current and future super-ageing societies in many countries, it is important to promote a physically active lifestyle during young adulthood to prevent the future development of functional limitations such as sarcopenia and frailty. Several consensus statements have recommended engagement in regular physical activity (PA) at specific exercise intensity, such as moderate-to-vigorous PA (MVPA), to enhance health and longevity (Saris et al. 2003; Haskell et al. 2007; Ishikawa-Takata and Tabata 2007). In particular, a number of international and national authorities have recommended that adults undertake at least 150 min a week of MVPA, i.e. MVPA for a minimum of 30 min on five days each week (Haskell et al. 2007) to obtain health benefits (Tremblay et al. 2011; Department of Health Physical Activity Health Improvement and Protection 2011; US Department of Health and Human Services 2008; World Health Organization 2010). Contrarily, the Japanese recommendation for PA is to undertake a total of 23 metabolic equivalents (METs) \times hour per week of MVPA (METs \times h/w) (Ministry of Health Labour and Welfare of Japan, 2006; 2013); this is more than double the 150 min per week of MVPA recommended elsewhere. It is widely accepted that the minimal and optimal intensities to improve cardiorespiratory fitness are at around 50% of maximal oxygen uptake or at the lactate threshold (LT), respectively (Tanaka and Shindo 1992; Tanaka et al. 1997; Ayabe and Ishii 2014). Thus, MVPA defined as an absolute intensity of ≥ 3 METs does not guarantee an improvement in cardiorespiratory fitness, and an individualised PA cut-off point may be more representative of an individual's PA level relative to their fitness capacity (Ayabe and Ishii 2014). Improving cardiorespiratory fitness requires increased time spent in PA at the LT intensity or above (\geq LT) under free-living conditions.

The number of steps taken in a day (STEP) is a popular method for evaluating PA levels in large population studies (Tudor-Locke et al. 2010; Aoyagi and Shephard 2013; Shephard et al. 2013) and for establishing alternative standard recommendations for PA (Tudor-Locke and Bassett 2004; Jordan et al. 2005; Tudor-Locke et al. 2011a). Indeed, governments, agencies and professional organisations around the world have developed various recommendations based on STEP (Tudor-Locke et al. 2011a; Tudor-Locke et al. 2011b; Ministry of Health Labour and Welfare of Japan, 2013). Several cross-sectional studies have found relationships between STEP and the duration of MVPA or the volume of MVPA undertaken (calculated as intensity in METs multiplied by the time spent at that intensity, METs×h) (Miller and Brown 2004; Ayabe et al. 2008b; Kumahara et al. 2008; Murakami et al. 2012; Oshima et al. 2012; Cao et al. 2014). A recent study confirmed that STEP could be used to quantify MVPA; this was based on both linear regression analysis and receiver operating characteristic methodology, with both analyses providing similar STEP thresholds equivalent to accumulating ≥ 150 min/w of MVPA (approximately 7700 to 8000 steps/d) and 23 METs×h/w (approximately 10,000 to 11,000 steps/d) (Cao et al. 2014). However, there appeared to be variation among individuals in the extent they deviated from these estimates, i.e. the classification accuracy of optimal STEP thresholds were 75% to 91% for ≥ 150 min/w and 79% to 93% for 23 METs×h/w depending on sex and age.

Limited information is available regarding the causes of individual variations in these STEP and MVPA relationships. We hypothesized that one of the causes of individual variations is related to the individual differences in the time spent for each intensity of PA per entire daily PA because a step count may not always provide accurate information on the intensity (Kumahara et al. 2009). Furthermore, no previous research has established whether STEP can be used to estimate the duration of \geq LT undertaken. The purpose of this study was to investigate the relationships between STEP and the duration and volume of MVPA and between STEP and the duration of \geq LT, under

free-living conditions.

Materials and methods

Participants

The study enrolled 70 healthy young adult Japanese women, aged 22.3 ± 2.1 years (range 20–29 years) and with body mass index of 20.3 ± 1.7 kg/m². All read and signed an informed consent form before participating in the study. The study was approved by the Ethical Committee of Nakamura Gakuen University.

Study protocol and PA analysis

Each participant's free-living PA was assessed over a 7-day period using an accelerometer. The participant was instructed to keep the accelerometer (Lifecorder EX-4sec, Suzuken Co., Nagoya, Japan) rigidly fixed to her waist continuously throughout the day, except while sleeping or bathing. The device's cover was sealed so that the participant was unable to access the display. In addition, the participant was required to self-report during the time she was not wearing the device or sleeping, completing a 10-min interval log from the time when the accelerometer was removed. The participant returned the accelerometer and the log directly to a researcher to confirm her compliance with completing the log. All participants consented to completing the log. The accelerometer has previously been validated for assessing PA-related energy expenditure and intensity (in METs) through comparison with indirect calorimetry (Kumahara et al. 2004), and it has been shown to count STEP more accurately than other instruments under both controlled (Crouter et al. 2003; Ayabe et al. 2008a) and free-living conditions (Schneider et al. 2004). Details of the device are available elsewhere (Kumahara et al. 2004). Based on the amplitude and frequency of the accelerometer signals, the device determines the level of the participant's activity as one of 11 levels (0, 0.5 and 1–9) and then converts this to the MET equivalent every 4 s. Level 1

approximates to 1.8 METs, and 0.5 is an arbitrarily ascribed value for when small movements are detected. The accelerometry levels allow an assessment of the time spent engaging in light (LPA; levels 1 to 3), moderate (levels 4 to 6) and vigorous-intensity PA (levels 7 to 9). MVPA can be also computed (levels 4 to 9). METs \times h was calculated using the total time spent at each accelerometry level ranging from 4 to 9, converted to the MET equivalent. The participant's LT (in METs) was assessed using an exercise test (described below), and the time spent at \geq LT was evaluated from the total time spent at accelerometry levels above that intensity. Sedentary activity (SA) was defined as the time spent below accelerometry level 1 (i.e. <1.8 METs), except for times the device was not worn and time spent sleeping, as assessed by the self-reported log. The percentage of time spent at each level of PA (%SA, %LPA, %MVPA and \geq LT) during the entire time that the accelerometer was worn was also computed.

The minimal accelerometer-wear criterion for a day to be considered valid followed that used in previous studies (Masse et al. 2005; Troiano et al. 2008), requiring accelerometer data to be recorded for 60% of the time the participant was awake; for example, if a participant slept about 8 hours/day, this corresponded to 60% of 16 hours of awake time, or a little less than 10 h/d of wear (Masse et al. 2005). In addition, the participant's data were considered valid only if she wore the accelerometer for a minimum of 4 days, including at least 3 weekdays and a minimum of 1 weekend day (Troiano et al. 2008). Weekly average values for the accelerometer data were calculated by weighting for 5 weekdays and 2 weekend days as follows:

$$\text{Weighted data} = (\text{average for weekdays} \times 5) + (\text{average for weekend days} \times 2) / 7$$

Each participant's LT intensity (in METs) was measured using a submaximal incremental exercise bench-stepping test, according to a method reported in previous studies (Ayabe et al. 2003; Ayabe et al. 2004). In brief, the blood lactate concentration was measured during the exercise test (4 min per stage with a rest period of about 2 min between consecutive stages). Thereafter, the LT intensity,

where the blood lactate just increased from baseline level, was determined individually.

Statistical analysis

Data are expressed as the mean \pm standard deviation. Pearson's correlation coefficients (r) were used to evaluate the relationship between STEP (steps/d) and MVPA (min/w), METs \times h/w, vigorous-intensity PA (min/w) or \geq LT duration (min/w). Based on these two relationships, we calculated the percentage to which each participant's individual STEP deviated from the linear equations based on average weekly values for the MVPA indices:

$$\% \text{deviation in STEP} = 100\% \times (\text{Estimated STEP from the linear equation} - \text{Average measured weekly STEP}) / \text{Average measured weekly STEP}$$

Automated multiple stepwise regression analysis was then used to determine the contribution to this percent deviation based on two sets of independent variable: height, body weight and body mass index with either the percentage of total time spent at LPA, MVPA, SA and \geq LT or the total durations (in minutes per week) of these exercise intensities. The product correlation coefficient (r^2) and standardised partial regression coefficient (β) were also calculated.

We also calculated for each participant the individual cut-off values of STEP that were equivalent to 150 min/w of MVPA or to 23.0 METs \times h/w from the regression equations between STEP and each MVPA index over a 7-day period. A cut-off STEP value for achieving 150 min/w of MVPA and 23.0 METs \times h/w could be estimated when there was a significant ($p < 0.05$) or tentative ($p < 0.1$) positive relationship between the regression equations (**Figure 1**). We then calculated correlation coefficients among %MVPA, %LPA and %SA and the individual cut-off STEP values equivalent to 150 min/w of MVPA and 23.0 METs \times h/w to determine the contribution for cut-off STEP with context for each intensity of daily PA.

Statistical analyses were performed using IBM SPSS Statistics version 23.0 (IBM Corp., Armonk,

NY, USA), A p -value <0.05 was considered significant, unless otherwise noted.

Results

High compliance in wearing the accelerometer was observed, with the device worn for a mean of $95.1\% \pm 4.3\%$ of the participants' awake time. Across the entire study period, the percentages of number of valid days was $99.4\% \pm 3.8\%$. The mean LT across all the participants was 5.8 ± 1.0 METs (range 3.8–8.3 METs). The mean values for STEP, SA, LPA, MVPA, METs \times h and \geq LT were 9324 ± 2677 steps/d, 6136.2 ± 546.4 min/w (876.6 ± 78.1 min/d), 435.6 ± 133.6 min/w (62.0 ± 19.2 min/d), 231.9 ± 101.5 min/w (33.1 ± 14.5 min/d), 16.6 ± 7.4 METs \times h/w and 24.0 ± 22.2 min/w (3.4 ± 3.2 min/d), respectively. Significant correlations were found between STEP and MVPA duration and STEP and METs \times h/w ($r = 0.805$ and $r = 0.806$, respectively; **Figure 2**). STEP equivalent to 150 min/w of MVPA and 23 METs \times h/w were estimated to be 7583 steps/d and 11,198 steps/d, respectively; however, approximately 1600 steps/d of the standard error of estimates in the regression equations were found (Figure 2). A significant but weak relationship existed between STEP and vigorous-intensity PA alone ($r = 0.529$, $r^2 = 0.280$, $p < 0.01$; time duration allocated for vigorous intensity was 19.6 ± 14.0 min/w: 2.8 ± 2.0 min/d). In contrast, no significant relationships were observed between \geq LT duration and STEP, MVPA or METs \times h/w (**Figure 2 and Appendix**).

In multiple stepwise regression analysis that included height, weight, body mass index and LPA, MVPA, SA and \geq LT, expressed as percentages of the total time during which the accelerometer was worn, the two common parameters of %LPA and %MVPA were significant determinants of the percent deviation in STEP from the linear equations describing the relationships between STEP and MVPA min/w or METs \times h/w (**Table 1**). In an analysis with these calculated variables expressed as time duration (minutes per week), LPA was identified to be significant main determinant (**Table 1**). Individual cut-off values for STEP equivalent to 150 min/w of MVPA and 23.0 METs \times h/w were

obtained from regression equations between STEP and each MVPA measure for the 7 days (an example is shown in **Figure 1**). Significant ($p < 0.05$) or tentative ($p < 0.1$) positive relationships between these variables were observed for 54 participants ($r = 0.774$ – 0.993) when MVPA min/w was used as the dependent variable, and for 52 participants when METs×h/w was used as the dependent variable ($r = 0.810$ – 0.991). As shown in **Figure 3**, when the participants were pooled, significant negative correlations were found among the individual estimated STEPs for achieving the MVPA guidelines and %MVPA ($r = -0.299$ and -0.549), and significant positive correlations were found for %LPA ($r = 0.778$ and 0.476). A significant correlation was observed between %SA and the estimated STEPs equivalent to 150 min/w of MVPA. In contrast, no significant relationship was observed for % \geq LT.

Discussion

This study explored whether STEP is an adequate indicator for assessing if an individual is meeting the MVPA guidelines; it also assessed the duration of \geq LT under free-living conditions. The findings indicated that the association between STEP and MVPA varies according to the proportion of PA time an individual spends engaging in LPA as well as in MVPA. Both multiple stepwise regression analysis (**Table 1**) and analysis using individual cut-off STEP values (**Figure 3**) showed that individuals with a high level of daily MVPA or a low level of daily LPA can achieve the guideline level of MVPA with a lower value of STEP. There was no significant correlation between STEP and the time spent in \geq LT. Thus, STEP alone may not be sufficient as an indicator of the duration of PA at \geq LT, as recommended for maintaining cardiorespiratory fitness, in young women. Many previous studies have reported meaningful relationships between STEP and MVPA indices (Miller and Brown 2004; Ayabe et al. 2008b; Kumahara et al. 2008; Murakami et al. 2012; Oshima et al. 2012; Cao et al. 2014), but with little information about inter-individual variability in these relationships. This is the first study to assess the causes of individual variations in relation to

the different time spent at each intensity of PA as proportions of the entire daily PA. These results are supported by a previous study (Kumahara et al. 2009) that indicated that STEP did not provide accurate information on the volume of PA; the total number of steps alone, rather than time series data, does not track PA volume (i.e. intensity \times duration).

Our study found significant relationships between STEP and the MVPA indices, as previously reported (Miller and Brown 2004; Ayabe et al. 2008b; Kumahara et al. 2008; Murakami et al. 2012; Oshima et al. 2012; Cao et al. 2014), which suggested that STEP could be used to define an alternative rough standard for the MVPA recommendations for young women. However, the number of steps per day estimated by various studies to be equivalent to 23 METs \times h/w for the Japanese population have varied across a relatively wide range, including 11,198 steps/d for our young female participants, 10,652 steps/d in a study including men and women (Kumahara et al. 2008), 9188 steps/d in a study of women (Murakami et al. 2012) and 8584 steps/d in a study of women who were only assessed for walking-related activity (Oshima et al. 2012). Moreover, as per a recent study, approximately 10,000 to 11,000 steps/d represent the optimal thresholds for likelihood of accumulating 23 METs \times h/w of MVPA, using two different analytical models of both linear regression analysis and receiver operating characteristic methodology (Cao et al. 2014). These results indicated that the relatively large variation in individual STEP levels corresponding to the target MVPA levels should be noted, although the Japanese PA recommendation set approximately 8,000–10,000 steps/day as an alternative goal to 23 METs \times h/w (Ministry of Health Labour and Welfare of Japan, 2006; 2013). The regression analyses for STEP and the MVPA indices implied approximately 1600 steps/d of the standard error of estimates from the regression equations (**Figure 2**). The results of multiple stepwise regression analyses and an analysis based on individual cut-off STEP values suggested that this was the result of individual differences in the proportions of time spent on MVPA or LPA each day. In addition to individual lifestyle factors,

physiological characteristics including age may also affect the variation in targeted STEP, because the proportion of total PA allocated to MVPA is influenced by aging (Ayabe et al. 2009) and by exercise habit (PA intervention) (Ayabe et al. 2010).

Importantly, the young women participants, who were not athletes and had no typical exercise habit, spent very little time on \geq LT (only about 3 min/day on average) under free-living conditions. Such a population should increase the time spent engaging in \geq LT, because the LT is widely accepted as the optimal relative intensity for improving cardiorespiratory fitness (Tanaka and Shindo 1992; Tanaka et al. 1997; Ayabe and Ishii 2014). Improved cardiorespiratory fitness has been shown to lead to reduced risks of non-communicable diseases, overall mortality and future functional limitations such as frailty (Haskell et al. 2007; Ishikawa-Takata and Tabata 2007; Kodama et al. 2009; Lee et al. 2012; Ministry of Health Labour and Welfare of Japan, 2013). Our participants' mean level of LT (5.8 METs) was almost double the 3 METs that defines the lower limit of MVPA and varied widely (range 3.8–8.3 METs), so an absolute intensity of MVPA does not guarantee improvements in cardiorespiratory fitness. Our results indicated that STEP did not relate to the time spent in \geq LT real-life conditions, so direct observation of \geq LT is required when undertaking PA intended to increase cardiorespiratory fitness. Setting a minimum PA cut-off level for an individual according to their PA level relative to their fitness capacity could be more beneficial than using an absolute, population-based PA cut-off level (Ayabe and Ishii 2014).

One of the limitations of this study was the sample population: only healthy young women were enrolled. However, this has the merit of providing results without age- and sex-related effects. Further studies are needed with participants of different ages, sex and health status.

In conclusion, this study showed that, in young adult women, the association between STEP and MVPA varies according to the amount of time the individual spends on MVPA and LPA each day. Furthermore, the time spent on activity \geq LT was not correlated with STEP. Consideration of both

the total daily STEP and the duration of habitual daily PA spent at a specific intensity are needed to improve the quantity and level of PA to meet the guidelines and thus to gain the associated health benefits. However, future studies are needed to investigate the effects on health outcomes of increasing PA using various PA indicators.

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HK and AM conceived and designed the study. HK took responsibility for the integrity of the data and accuracy of the data analysis, and wrote the original manuscript. All authors have read and approved the final version of the manuscript, and agree with the order of presentation of the authors.

Conflict of interest statement

The authors have no conflicts of interest to disclose.

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Captions

Figure 1. Example calculation of cut-off values for the number of steps per day equivalent to 150 min/week MVPA and 23 METs×hour/week.

Regression equations between steps per day (STEP) and each MVPA index over a 7-day period were computed. In this example (participant HS), significant relationships were observed and STEP values equivalent to achieving 150 min/w MVPA and 23 METs×h/w were estimated to be 7897 and 12,418 steps/d, respectively.

MVPA: moderate-to-vigorous intensity physical activity (intensity ≥ 3 METs)

Figure 2. Relationships between the number of steps per day and the MVPA indices (Upper: minutes per week; Middle: METs×hour per week) or \geq LT (Lower: minutes per week) ($n = 70$).

There were significant correlations for MVPA indices.

MVPA: moderate-to-vigorous intensity physical activity (intensity ≥ 3 METs); \geq LT: physical activity at the lactate threshold intensity or above; SEE: standard error of estimates from the regression equation.

Figure 3. Relationships among MVPA, LPA, SA and \geq LT, expressed as percentages of the total time during which the accelerometer was worn and individual cut-off step counts equivalent to the physical activity guidelines.

For some participants, the relationships between steps per day and the MVPA indices over 7 days were not statistically significant. We were therefore unable to calculate the cut-off step counts equivalent to 150 minutes per week of MVPA for 16 participants and to 23 METs×hr per week for

18 participants.

%LPA: percentage of time spent in light-intensity physical activity; %MVPA: percentage of time spent in moderate-to-vigorous intensity physical activity (intensity ≥ 3 METs); %SA: percentage of time spent in sedentary activity; $\% \geq \text{LT}$: percentage of time spent in physical activity at the lactate threshold intensity or above.

Appendix. Relationships between the $\geq \text{LT}$ and the MVPA indices (Upper: minutes per week; Lower: METs \times hour per week).

There were no significant correlations for MVPA indices.

MVPA: moderate-to-vigorous intensity physical activity (intensity ≥ 3 METs); $\geq \text{LT}$: physical activity at the lactate threshold intensity or above.

Table 1. Multiple stepwise regression analyses for the percentage deviation of the measured values from the step counts estimated from linear equations for the relationships between steps per day and the MVPA indices.

| Dependent variable | A | β | | B | β | |
|--|-------------------|---------|-----|-------------------|---------|-----|
| % error in step counts from the linear equation related to MVPA minutes per week | Modeled variables | | | Modeled variables | | |
| | %LPA | -0.922 | *** | LPA | -0.947 | *** |
| | %MVPA | 0.162 | ** | Body weight | 0.112 | ** |
| | Body weight | 0.115 | * | MVPA | 0.093 | * |
| | r^2 0.808 * | | | r^2 0.881 *** | | |
| % error in step counts from the linear equation related to METsxhr per week | Modeled variables | | | Modeled variables | | |
| | %LPA | -0.925 | *** | LPA | -0.935 | *** |
| | %MVPA | 0.154 | ** | SA | -0.103 | * |
| | | | | Body weight | 0.087 | * |
| | r^2 0.794 ** | | | r^2 0.882 * | | |

The contributions to the percentage deviation from the estimated step count were calculated with two sets of independent variables:

A: Height, body weight, body mass index and LPA, MVPA, SA and \geq LT, expressed as percentages of the total time during which the accelerometer was worn. However, %SA was removed the analysis because collinearity among the explanatory variables was indicated by a high variance inflation factor value (VIF = 3.619).

B: Height, body weight, body mass index and the total time (minutes per week) at LPA, MVPA, SA and \geq LT.

LPA: light-intensity physical activity; MVPA: moderate-to-vigorous intensity physical activity (intensity \geq 3 METs);

SA: sedentary activity; LT: lactate threshold.

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$

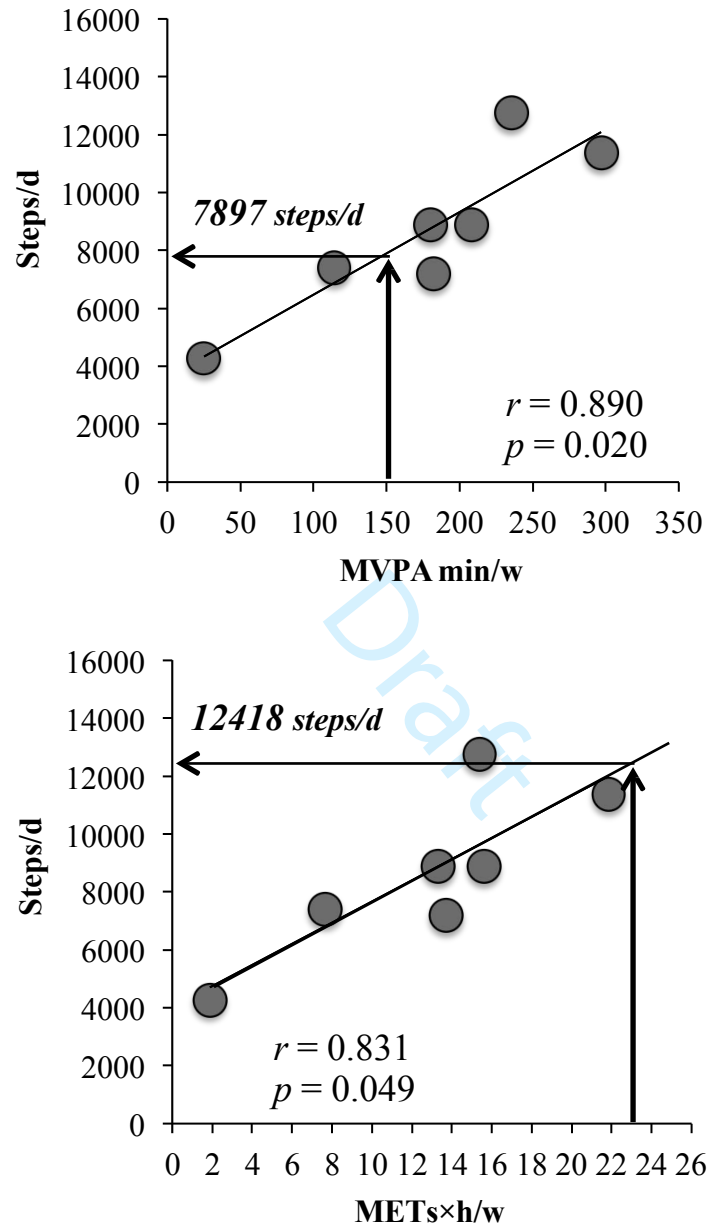
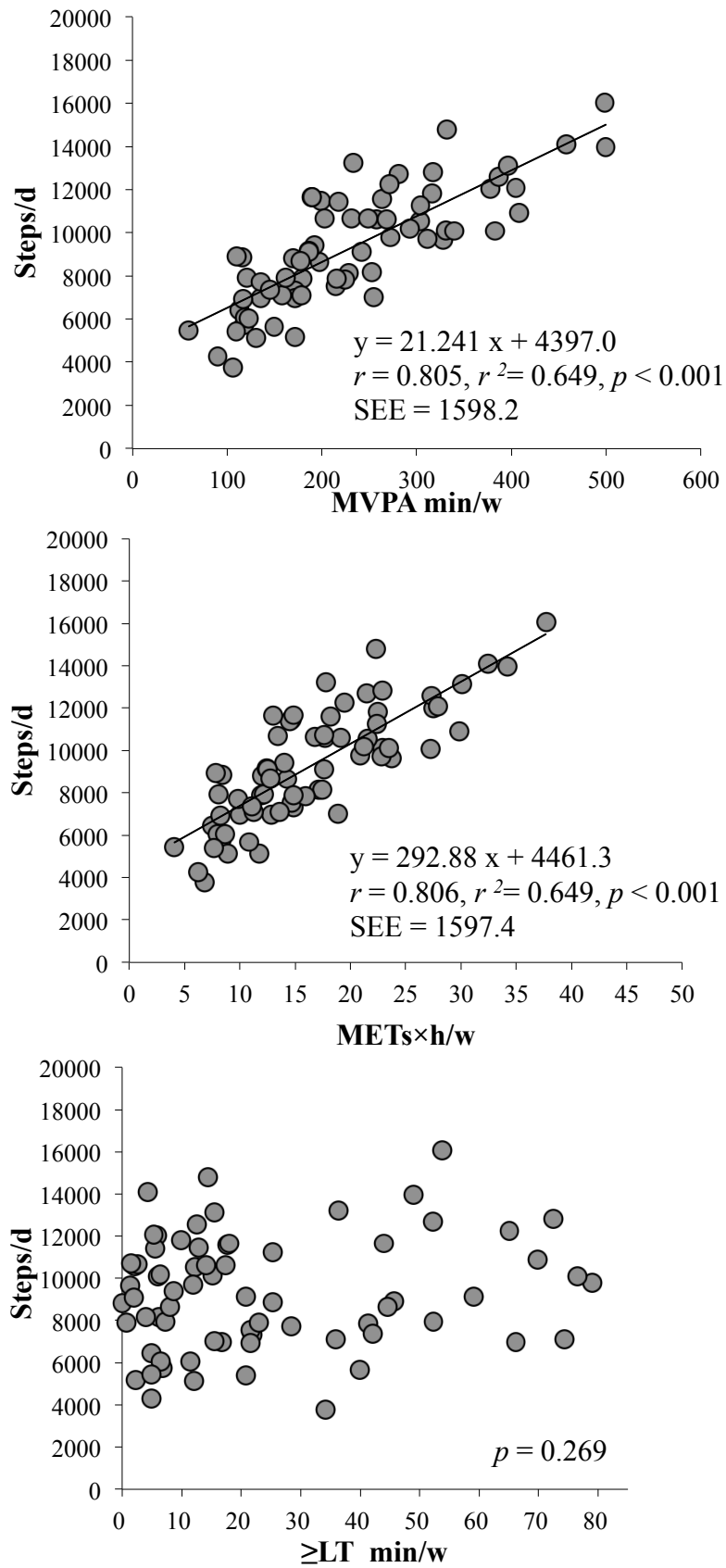
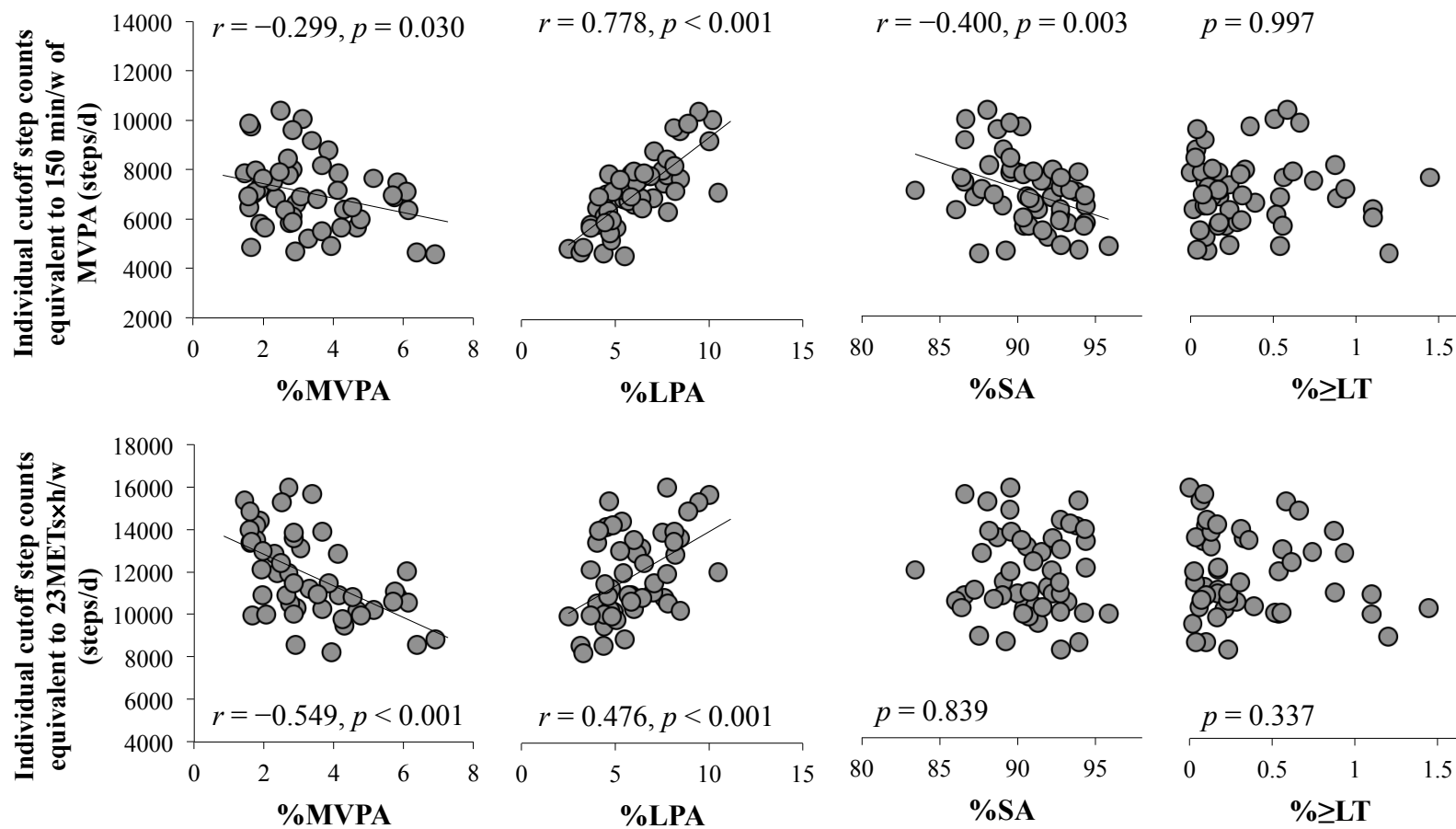
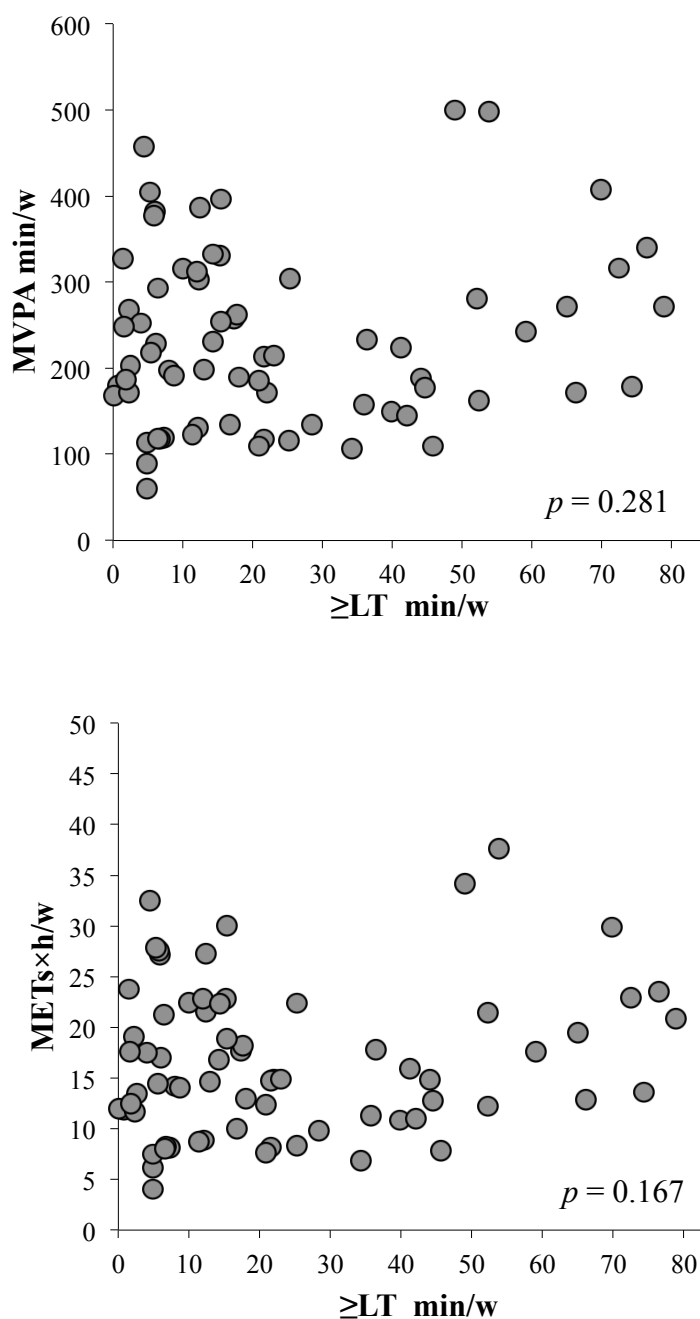


Figure 1.

**Figure 2.**

**Figure 3.**



(Appendix) Fig. A.1: Relationships between the \geq LT and the MVPA indices (Upper: minutes per week; Lower: METs×hour per week).

There were no significant correlations for MVPA indices.

MVPA: moderate-to-vigorous intensity physical activity (intensity ≥ 3 METs); \geq LT: physical activity at the lactate threshold intensity or above.