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Research article

Daily Step-Based Recommendations Related to Moderate-to-Vigorous Physical Activity and Sedentary Behavior in Adolescents

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Abstract

Among adolescents empirical studies examining the total daily steps translation of the moderate-to-vigorous physical activity recommendation are scarce and inconsistent, and there are no previous studies with cadence-based steps and related to sedentary behavior. The main objective of the present study was to establish and compare the accuracy of daily step-based recommendations related to the moderate-to-vigorous physical activity and sedentary behavior thresholds in adolescents. The present study followed a cross-sectional design. A total of 126 adolescents (56 girls) aged 12-15 years old were assessed by ActiGraph GT3X accelerometers for eight consecutive days (moderate-to-vigorous physical activity, sedentary behavior, and steps) and the multistage 20-meter shuttle run test (cardiorespiratory fitness). ROC curve analyses showed that total daily steps (AUC = 0.94, 0.89-0.99; Threshold ≥ 11,111 steps/ day; $P = 0.93$; $k = 0.67$; $p < 0.001$) was a more appropriate indicator than cadence-based daily steps for distinguishing between physically active and inactive adolescents. Daily step-based thresholds represent a promising way to translate a total daily sedentary behavior threshold (e.g., total daily steps, AUC = 0.87, 0.81-0.93; Sensitivity = 0.87; Specificity = 0.70). Adolescents who met a favorable combination of step-based recommendations related to both physical activity and sedentary behavior thresholds had a higher probability of having a healthy cardiorespiratory fitness profile than those who did not meet either of them (e.g., risk ratio = 5.05, 1.69-15.08) or only the one related to physical activity (e.g., risk ratio = 4.09, 1.36-12.29). These findings may help policy-makers to provide accurate daily step-based recommendations that would simplify the physical activity and sedentary behavior thresholds for adolescents.

Key words: Steps/ day, step counts, walking cadence, cut-off point, thresholds, children.

Introduction

Physical inactivity is widely recognized as a health indicator in adolescents (Poitras et al., 2016). Independently of physical activity (PA) levels, a high amount of sedentary behavior (SB) among adolescents is also related to an augmented risk of several negative health outcomes such as unfavorable body composition, cardiometabolic status or physical fitness (Carson et al., 2016). Therefore, adolescents who devote a large amount of their waking time to SB will augment the risk of having health issues, even those who engage in regular PA (Santos et al., 2014). Regrettably, worldwide about 81% of adolescents are physically inactive (World Health Organization, 2014) and, on average, they also spend over two-thirds of the waking day engaging in SB (Ruiz et al., 2011).

Currently a key public health priority is to decrease the number of adolescents physically inactive and engaging in high amounts of SB (Department of Health, Physical Activity, Health Improvement and Protection, 2011; World Health Organization, 2014). The World Health Organization (2010) recommends that adolescents should achieve daily at least 60 minutes of moderate-to-vigorous PA (MVPA) involving mainly a variety of aerobic activities such as brisk walking or running. In addition to adhering to the MVPA recommendation, public health guidelines for young people also have recently incorporated recommendations about SB such as limiting the time spent in recreational screen activities, motorized transport or indoors during the waking day (Tremblay et al., 2016). Unfortunately, to our knowledge, today there is not any quantitative public health guidelines about total daily SB (for an in-depth discussion about the topic, please see Stamatakis et al., 2018).

Nowadays there is a growing interest in establishing daily step-based recommendations related to public health guidelines among young people (Tudor-Locke et al., 2018; Tudor-Locke et al., 2011). On the one hand, public health guidelines expressed in terms of type, frequency, duration, and intensity are not easily understood by both adolescents and their parents (Tudor-Locke et al., 2011). For instance, previous empirical studies have shown how most adolescents and adults have a low ability to correctly interpret and identify daily activities with MVPA intensity (Crossley et al., 2019; Knox et al., 2013). Instead, the commonly used total daily steps represent a simply output to assess PA (Althof et al., 2017; Tudor-Locke et al., 2011). On the other hand, since consumer-wearable step-based monitors such as smart activity bands or Smartphone apps are characterized to be unobtrusive, cheap and intuitive (Baumgartner et al., 2015), for about the last 10 years the use of these monitors has become very popular (Althof et al., 2017).

Unfortunately, empirical studies examining the total daily steps translation of the 60 min MVPA recommendation in adolescents are scarce and inconsistent (Adams et al., 2009; Adams et al., 2013; Benítez-Porres et al., 2016; Colley et al., 2012; Fontana et al., 2015). Although the total daily step-based recommendations have the advantage of being very simple to understand, total daily steps assess the volume of PA, but they do not assess intensity, which is an important constituent of public health guidelines (Tudor-Locke et al., 2018). Steps cadence is related to intensity

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and, thus, establishing daily cadence-based steps recommendations such as the total time or steps spent above a particular cadence would be more precise (in contrast, it could complicate its interpretation compared with the total daily steps output) (Tudor-Locke et al., 2011). However, to our knowledge there are no previous studies establishing daily cadence-based steps thresholds. Additionally, unlike the evidence to support a step-based recommendation related to SB among adults (Tudor-Locke et al., 2013), as far as we know to date no study has examined the step-based recommendations related to SB among adolescents. Finally, due to the demonstrated strong and favorable relationship between habitual PA/ non-SB levels and healthy cardiorespiratory fitness status among young people (Poitras et al., 2016; Carson et al., 2016), the validity of the proposed step-based cut-off points to distinguish between healthy and unhealthy cardiorespiratory fitness status should also be examined. Consequently, the main objective of this study was to establish and compare the accuracy of daily step-based recommendations related to MVPA and SB thresholds in adolescents. The secondary purpose was to compare the maximum oxygen uptake (VO_2max) levels between adolescents who met and did not meet the daily step-based recommendations.

Methods

Participants

The present study is reported according to the STROBE guidelines (von Elm et al., 2007). The protocol conforms to the Declaration of Helsinki statements (64th WMA, Brazil, October 2013). The protocol of the study was first approved by the Ethical Committees for human studies of the authors' institutions. Then, all the 10 public school centers of basic education level belonging to the district called Nuñoa were invited to participate; Nuñoa is an urban area situated at the Northeastern sector of the city of Santiago (Chile), which is mainly composed of families with a middle-high and high socioeconomic status. The principals and the physical education teachers were informed about the project and the permission to conduct the study was requested. After four schools agreed to participate, eighth-grade students and their legal guardians were fully informed about the project. Adolescents' written informed assent and their legal guardians' written informed consent to take part in the study were obtained before participating. Recruitment was carried out from March (third week) to April (last week) of 2015, and data collection from July (first week) to October (first three weeks) of 2015.

The present study followed a cross-sectional design. One hundred and fifty-six adolescents (87 boys and 69 girls) aged 12-15 years old agreed to participate and met the inclusion criteria. The inclusion criteria were: (a) being registered in the eighth grade of any chosen center; (b) being free of any health disorder which would make them unable to engage in PA; (c) presenting the corresponding signed written informed assent by the adolescents, and (d) presenting the corresponding signed written informed consent by their legal guardians. However, since 30 students (17 boys and 13 girls) met at least one exclusion criterion, finally only 126 participants (70 boys and 56 girls) were analysed (i.e., non-compliance rate equal to 19.2%). The exclusion criteria were: (a) not having at least two weekdays with the valid wear time, and (b) not having at least one weekend day with the valid wear time. Table 1 shows the general characteristics of the analysed participants. A priori sample size calculation was estimated with the MedCalc Statistical Software version 19.0.3 (MedCalc Software bvba, Ostend, Belgium). Parameters were set in a conservative manner as follows: Type I error (Alpha) = 0.05, Type II error (Beta) = 0.20, area under the ROC curve = 0.70 (Mandrekar, 2010), null hypothesis value = 0.50, and ratio of sample sizes = 0.19 (World Health Organization, 2014). A minimum final sample size of about 109 was estimated.

Measures

Physical activity and sedentary behavior. Adolescents' MVPA, SB and steps were objectively measured by ActiGraph GT3X accelerometers (Pensacola, FL, USA). Accelerometers were fitted by an elastic waistband on the adolescents' right hip. Adolescents were instructed to wear

Table 1. General characteristics of the analyzed participants

	Boys (*n* = 70)	Girls (*n* = 56)	Total (*n* = 126)
Age (years)	13.5 (0.7)	13.3 (0.6)	13.4 (0.7)
Body mass (kg)	59.1 (11.6)	56.9 (9.2)	58.1 (10.6)
Body height (cm)	166.4 (7.7)	159.7 (5.5)	163.4 (7.6)
Body mass index (kg/ m^2)	21.3 (3.5)	22.3 (3.4)	21.7 (3.5)
Overweight/ obesity (no/ yes)	70.0/ 30.0	62.5/ 37.5	66.7/ 33.3
Waist circumference (cm)	76.3 (9.5)	73.8 (8.6)	75.2 (9.2)
Excess central body fat (no/ yes)	78.6/ 21.4	87.5/ 12.5	82.5/ 17.5
VO_2max (ml/ kg/ min)	42.4 (5.0)	38.0 (4.2)	40.4 (5.2)
Healthy cardiorespiratory fitness (yes/ no)	48.6/ 51.4	37.5/ 62.5	43.7/ 56.3
Daily MVPA (min)	38.0 (21.7)	24.8 (16.2)	32.1 (20.5)
≥ 60 min daily MVPA (yes/ no)	15.7/ 84.3	3.6/ 96.4	10.3/ 89.7
Daily sedentary behavior (%)	69.6 (7.3)	71.6 (5.6)	70.5 (6.6)
< 69% of day in sedentary behavior (yes/ no)	57.1/ 42.9	41.1/ 58.9	50.0/ 50.0
Daily uncensored total steps (steps)	8946.8 (3127.5)	7756.8 (2320.6)	8417.9 (2849.8)
Daily censored total steps (steps)	7411.7 (2979.5)	6212.8 (2258.3)	6878.8 (2739.0)
Daily uncensored steps/ min (steps)	7.7 (2.6)	7.0 (2.1)	7.4 (2.4)
Daily censored steps/ min (steps)	41.7 (8.6)	41.4 (7.2)	41.5 (8.0)

MVPA, Moderate-to-vigorous physical activity; VO_2max, Estimated maximum oxygen uptake. [a] Data are reported as mean (standard deviation) or percentage the accelerometer for eight consecutive days from waking to bedtime. During the waking time, participants were asked to take it off only when they do aquatic activities or take a bath/ shower. Initialize, download, wear time validation and scoring were performed using the ActiLife software version 6.13.3 (ActiGraph, LLC). Step-based variables were calculated from raw steps by an *ad hoc* Microsoft Office Excel 2007 template (Microsoft® Corporation). Table 2 shows the description of the calculated step-based variables in the present study. To avoid potential biases due to adolescents' reactivity, the first monitored day was not used (Dössegger et al., 2014). Valid wear time was set as ≥ 600 min/ day (Migueles et al., 2017). Non-wear periods were set with ≥ 60 min of consecutive 0-count *epochs* with ≤ 2 min spike tolerance (Oliver et al., 2011). Time (in minutes) engaged in MVPA and SB was determined by the thresholds ≥ 2,296 *counts*/min and 0-100 *counts*/min, respectively (Evenson et al., 2008). According to the cross-validation study performed by Trost et al. (2011), these cut-off points have been found to be the most valid for estimating PA intensity among adolescents. Steps were calculated by within-instrument processing of *cycle counts*.

Afterward, habitual MVPA, SB and steps were calculated as follows: ((5 × mean value of valid weekdays) + (2 × mean value of valid weekend days))/ 7. Adolescents' habitual MVPA (i.e., weighted daily mean) was categorized as meeting or not meeting at least 60 min of MVPA (World Health Organization, 2010). Adolescents' habitual SB (i.e., weighted daily mean) was categorized as exceeding or not exceeding the daily threshold of 69% of waking time in SB (Martinez-Gomez et al., 2011). To our knowledge Martinez-Gomez et al. (2011) is the only research study that has tried to specify a total daily SB time threshold associated with a health marker in adolescents. Therefore, the SB threshold adopted in the present study (and consequently, the step-based thresholds related to that SB criteria) should be considered with caution (see discussion section). ActiGraph accelerometers have demonstrated high validity for assessing MVPA, SB and steps among adolescents (Arvidsson et al., 2011; Trost et al., 2011).

Table 2. Description of the step-based variables used in the present study.

Name	Description
Uncensored total steps	Total number of steps recorded during a whole day
Censored total steps	Total number of steps recorded during a whole day by censoring those steps taken below 500 *counts*/ min. These adjusted steps might be more comparable to consumer-wearable activity monitors output (see discussion section)
Uncensored steps/ min	Uncensored total steps divided by the total number of minutes recorded during a whole day
Censored steps/ min	Censored total steps divided by the total number of minutes recorded during a whole day
Minutes ≥ 40 steps/ min	Total number of minutes per day accumulated within minutes with a cadence equal or over 40 steps/ min. Due to the variability outcomes in the previous laboratory-based studies establishing a cadence related to moderate PA among young people, step-per-minute rates from 40 to 140 increasing by 5 steps were calculated
Steps ≥ 40 steps/ min	Total number of uncensored steps per day accumulated within minutes with a cadence equal or over 40 steps/ min. Step-per-minute rates from 40 to 140 increasing by 5 steps were calculated
PC min ≥ 40 steps/ min	Percentage of total number of minutes per day accumulated within minutes with a cadence equal or over 40 steps/ min. Step-per-minute rates from 40 to 140 increasing by 5 steps were calculated
PC steps ≥ 40 steps/ min	Percentage of total number of uncensored steps per day accumulated within minutes with a cadence equal or over 40 steps/ min. Step-per-minute rates from 40 to 140 increasing by 5 steps were calculated
Peak 1-min cadence	Total number of uncensored steps accumulated during the highest single minute in a whole day
Peak 30-min cadence	Average of the uncensored steps/ min accumulated during the highest, but not necessarily consecutive, 30 minutes of the whole day
Peak 60-min cadence	Average of the uncensored steps/ min accumulated during the highest, but not necessarily consecutive, 60 minutes of the whole day
Minutes 0 steps/ min	Total number of minutes per day accumulated within minutes with a cadence equal to 0 steps/ min
Minutes < 5 steps/ min	Total number of minutes per day accumulated within minutes with a cadence below 5 steps/ min. Due to the lack of previous laboratory-based studies establishing a cadence related to sedentary, step-per-minute rates from 5 to 40 increasing by 5 steps were calculated
Steps < 5 steps/ min	Total number of uncensored steps per day accumulated within minutes with a cadence below 5 steps/ min. Step-per-minute rates from 5 to 40 increasing by 5 steps were calculated
PC minutes 0 steps/ min	Percentage of total number of minutes per day accumulated within minutes with a cadence equal to 0 steps/ min
PC minutes < 5 steps/ min	Percentage of total number of minutes per day accumulated within minutes with a cadence below 5 steps/ min. Step-per-minute rates from 5 to 40 increasing by 5 steps were calculated
PC steps < 5 steps/ min	Percentage of total number of uncensored steps per day accumulated within minutes with a cadence below 5 steps/ min. Step-per-minute rates from 5 to 40 increasing by 5 steps were calculated
Minutes 0 steps/ min (bouts)	Total number of minutes per day accumulated in bouts of at least 10 min within minutes with a cadence equal to 0 steps/ min
Minutes < 5 steps/ min (bouts)	Total number of minutes per day accumulated in bouts of at least 10 min within minutes with a cadence below 5 steps/ min. Step-per-minute rates from 5 to 40 increasing by 5 steps were calculated
PC minutes 0 steps/ min (bouts)	Percentage of total number of minutes per day accumulated in bouts of at least 10 min within minutes with a cadence equal to 0 steps/ min
PC minutes < 5 steps/ min (bouts)	Percentage of total number of minutes per day accumulated in bouts of at least 10 min within minutes with a cadence below 5 steps/ min. Step-per-minute rates from 5 to 40 increasing by 5 steps were calculated
Steps bottom 600 min	Average of the uncensored steps accumulated during the lowest, but not necessarily consecutive, 600 minutes of the whole day. Rates from 60 to 600 increasing by 60 minutes were calculated

PC, Percentage.

Anthropometric. Adolescents' body mass, body height and waist circumference were assessed following the International Standards for Anthropometric Assessment (Stewart et al., 2011). Then, body mass index was calculated as body mass (in kilograms) divided by the square of body height (in meters) (kg/ m^2). Finally, participants' body weight and central body fat status were categorized by the body mass index and waist circumference thresholds, respectively (Cole et al., 2000; Gómez-Campos et al., 2015). Body mass index and waist circumference have shown high validity for assessing body composition among adolescents (Castro-Piñero et al., 2010).

Maximum oxygen uptake. Participants first performed the multistage 20-meter shuttle run test (the starting speed of 8.5 km/h increased by 0.5 km/h about each minute) (Léger et al., 1988). Then, participants' VO_2max (ml/kg/min) was estimated as follows: 31.025 + 3.238 x speed (in km/ h) – 3.248 x age (in years) + 0.1536 x speed (in km/ h) x age (in years) (Léger et al., 1988). Finally, according to the VO_2max cut-off points, participants were categorized as having a healthy and unhealthy cardiorespiratory fitness level (i.e., "healthy cardiorespiratory fitness level" when the VO_2max value was equal or above the sex- and age-related healthy fitness zone, and "unhealthy cardiorespiratory fitness level" when the VO_2max value was below the sex- and age-related healthy fitness zone; among 12-to-15-year-old adolescents the VO_2max values are 40.3-43.6 for boys and 40.1-39.1 for girls) (Welk et al., 2011). The multistage 20-meter shuttle run test and Leger's equation have shown adequate validity for assessing cardiorespiratory fitness among adolescents (Léger et al., 1988; Mayorga-Vega et al., 2015).

Procedures

All measurements were carried out during the physical education class time by the same evaluator, instruments and protocols. In the first week, the accelerometers were fitted by an elastic waistband on the adolescents' right hip. Participants were urged to continue with their habitual PA levels during the monitoring period (i.e., eight consecutive days including the day that accelerometers were fitted). In the second week, the accelerometers were collected. In the third week, anthropometric measurements were carried out, and then some days later in the next physical education session, adolescents performed the multistage 20-meter shuttle run test in an indoor sports facility with a non-slippery floor. Previous to the multistage 20-meter shuttle run test, adolescents carried out a five-minute warm-up consisting of running from low to moderate intensity. Participants' gender and age information was obtained from the school reports.

Statistical analysis

All the statistical analyses performed in this study were based on the habitual MVPA, SB and step-based variables (i.e., the daily weighted mean). Descriptive statistics (i.e., frequency, percentage, mean, median, standard deviation, and interquartile range) were first calculated. Then, Receiver Operating Characteristic (ROC) curve analyses with the Youden's index (J max = sensitivity + specificity - 1) were used to estimate the optimal daily step-based cut-off points associated with meeting or not meeting the daily MVPA and SB criteria (Hajian-Tilaki, 2013). Sensitivity (Se) was referred as the probability of correctly detecting adolescents that achieved the daily MVPA/ SB thresholds, while specificity (Sp) was referred as the probability of correctly detecting adolescents that did not achieve the daily MVPA/ SB thresholds. The area under the ROC curves (AUC), and their 95% confidence interval (95% CI), were also calculated. The accuracy of the obtained optimal daily step-based cut-off points was calculated as Percentage of agreement [P = agreements/ (agreements + disagreements)] and Kappa coefficient (k) (McHugh, 2012).

Afterward, the Mann-Whitney U test was used to compare the VO_2max levels between adolescents who met and did not meet the daily step-based recommendations. Effect sizes were estimated using the Rosenthal's r. Finally, the risk ratios (RR, also known as relative risk), with their 95% CI, were calculated to assess the probability among the adolescents achieving the daily step-based recommendations of having a healthy cardiorespiratory fitness profile compared to those who did not achieve them. Because of the low number of participants, all statistical analyses were carried out with boys and girls together. Due to the high number of cadence-based and steps bottom variables, only the most accurate values of each variable were reported. ROC figures could not be reported because of extension limits. All statistical analyses were performed using the SPSS version 21.0 for Windows (IBM® SPSS® Statistics) and Microsoft Office Excel 2007 (Microsoft® Corporation). The statistical significance level was set at $p \leq 0.05$.

Results

Step-based recommendations related to moderate-to-vigorous physical activity

Table 3 shows the cut-off points and accuracy of the daily step-based recommendations related to achieving at least 60 min of MVPA. 10.3% of the adolescents achieved at least 60 min daily MVPA, and 14.3-39.7% (median = 20.6%) of the adolescents achieved the proposed daily step-based recommendations. The accuracy of the total daily step-based recommendations was higher than for those with the cadence-based steps. Regarding the cadence-based steps, the variables ≥ 65 steps/ min and peak 1-min cadence showed the highest accuracy among the analysed rates.

Table 4 shows the comparison of estimated VO_2max levels between adolescents who met and did not meet the daily step-based recommendations related to achieving at least 60 min of MVPA. The adolescents that met the total daily step-based recommendations had healthier cardiorespiratory fitness levels than those that did not meet them. The variables ≥ 65 steps/ min (except for the percentage minutes variable) and the peak 1-min cadence showed the best result among the analysed rates.

Step-based recommendations related to sedentary behavior

Table 5 shows the cut-off points and accuracy of the daily step-based recommendations related to having less than 69% of the waking day in SB. 50.0% of the adolescents met the recommendation of having less than 69% of the waking day time in SB, and 1.6-65.9% (median = 50.0%) of the adolescents achieved the proposed daily step-based recommendations. The accuracy values of the thresholds based on the total daily steps variables was similar than for those thresholds based on the cadence steps variables. Among the analysed rates (e.g., step-per-minute rates from 0 to 40 increasing by 5 steps were calculated for cadence-based steps thresholds related to SB; see Table 2), the cadence 0 steps/ min, < 5 steps/ min and steps bottom 600 min showed the highest accuracy values.

Table 6 shows the comparison of estimated VO_2max levels between adolescents who met and did not meet the daily step-based recommendations related to having less than 69% of the waking day in SB. Statistically significant differences between the two profiles were not found ($p > 0.05$).

Step-based recommendations related to both moderate-to-vigorous physical activity and sedentary behavior

Table 7 shows the comparison of estimated VO_2max levels between adolescents who met and did not meet the daily step-based recommendations related to both MVPA and SB. The results showed that adolescents who met a favorable combination of step-based recommendations had a higher probability of having a healthy cardiorespiratory fitness profile than those who did not meet either of them. The combination of the thresholds based on the variables peak 1-min cadence and steps bottom 600 min showed the most favorable result ($r = 0.39$; RR = 5.05, 1.69-15.08).

Discussion

The main objective of this study was to establish and compare the accuracy of daily step-based recommendations related to MVPA and SB thresholds in adolescents. The accuracy of the daily step-based recommendations related to achieving at least 60 min of MVPA was higher for the total daily steps compared to cadence-based steps. Therefore, although the total daily steps do not assess intensity as the cadence-based steps do, steps recommendations based on total daily steps are preferable because they are not only simpler but also more accurate for classifying adolescents as meeting or not meeting the MVPA recommendation. Previous similar studies obtained a high variability steps thresholds, ranging from 9,701-14,000 uncensored total daily steps (Adams et al., 2009; Adams et al., 2013; Benítez-Porres et al., 2016; Colley et al., 2012). Similarly to previous review studies (i.e., 10,000-12,000 steps/ day) (Da Silva et al., 2015; Tudor-Locke et al., 2011), in the present study the 11,111 steps/ day threshold was found.

For about the last 10 years, the use of consumer-wearable step-based monitors has become very popular (Althof et al., 2017). In line with Tudor-Locke et al. (2010), in the present study the accelerometer-measured total daily steps (i.e., uncensored total daily steps) were adjusted (i.e.,

Table 3. Cut-off points and accuracy of the daily step-based recommendations related to achieving at least 60 min per day of moderate-to-vigorous physical activity.

Step-based index	Cut-off point	%TP	AUC (95% CI)	Se	Sp	*J* max	*P*	*k*
Uncensored total steps	11,111 steps	14.29	0.94 (0.89-0.99)†	0.85	0.94	0.78	0.93	0.67†
Censored total steps	8,606 steps	20.63	0.95 (0.90-1.00)†	0.92	0.88	0.80	0.88	0.55†
Uncensored steps/ min	8.7 steps/ min	26.19	0.92 (0.85-0.99)†	0.92	0.81	0.74	0.83	0.44†
Censored steps/ min	45.1 steps/ min	31.75	0.76 (0.60-0.92)‡	0.85	0.74	0.59	0.75	0.31†
Min ≥ 65 steps/ min	60 min	14.29	0.90 (0.80-1.00)†	0.77	0.93	0.70	0.91	0.60†
Steps ≥ 65 steps/ min	5,684 steps	15.87	0.89 (0.78-1.00)†	0.85	0.92	0.77	0.91	0.62†
PC min ≥ 65 steps/ min	4.9%	19.05	0.89 (0.79-1.00)†	0.85	0.88	0.73	0.88	0.53†
PC steps ≥ 65 steps/ min	55.0%	15.08	0.80 (0.63-0.97)†	0.69	0.91	0.60	0.89	0.50†
Peak 1-min cadence	124 steps	34.13	0.76 (0.61-0.91)‡	0.77	0.71	0.48	0.71	0.24‡
Peak 30-min cadence	86 steps	39.68	0.73 (0.59-0.88)‡	0.69	0.64	0.33	0.64	0.15*
Peak 60-min cadence	72 steps	32.54	0.78 (0.64-0.91)‡	0.62	0.71	0.32	0.70	0.17*

%TP, Percentage of total positive cases according to the specified cut-off point; AUC (95% CI), Area Under the Curve (95% confident interval); Se, Sensitivity; Sp, Specificity; *J* max, Youden's index; *P*, Percentage of agreement; *k*, Kappa coefficient; PC, Percentage. * $p < 0.05$, ‡ $p < 0.01$ and † $p < 0.001$.

Table 4. Comparison of estimated maximum oxygen uptake levels (ml/ kg/ min) between adolescents who met and did not meet the daily step-based recommendations related to achieving at least 60 min per day of moderate-to-vigorous physical activity

Step-based index	Cut-off point	Not meeting		Meeting		Mann-Whitney U test			RR (95% CI)[a]
		n	Mdn (IQR)	*n*	Mdn (IQR)	*Z*	*p*	*r*	
Uncensored total steps	11,111 steps	108	39.9 (7.9)	18	43.8 (7.2)	2.407	0.016	0.21	3.02 (1.06-8.67)
Censored total steps	8,606 steps	100	39.4 (7.9)	26	43.8 (7.2)	2.961	0.003	0.26	2.50 (1.03-6.07)
Uncensored steps/ min	8.7 steps/ min	93	39.4 (7.9)	33	41.1 (8.2)	1.487	0.137	0.13	1.54 (0.69-3.42)
Censored steps/ min	45.1 steps/ min	86	39.4 (7.9)	40	41.2 (9.6)	1.896	0.058	0.17	2.28 (1.06-4.90)
Min ≥ 65 steps/ min	60 min	108	39.4 (7.9)	18	43.8 (6.7)	2.977	0.003	0.27	4.09 (1.36-12.29)
Steps ≥ 65 steps/ min	5,684 steps	106	39.4 (7.9)	20	43.8 (6.4)	2.984	0.003	0.27	3.70 (1.32-10.39)
PC min ≥ 65 steps/ min	4.9%	102	39.9 (7.9)	24	42.5 (8.9)	1.911	0.056	0.17	2.08 (0.84-5.14)
PC steps ≥ 65 steps/ min	55.0%	107	41.1 (7.9)	19	43.8 (10.8)	2.346	0.019	0.21	3.35 (1.18-9.51)
Peak 1-min cadence	124 steps	83	38.5 (6.2)	43	43.8 (6.9)	4.131	< 0.001	0.37	3.87 (1.78-8.42)
Peak 30-min cadence	86 steps	76	39.0 (7.9)	50	41.2 (6.8)	2.177	0.030	0.19	2.31 (1.11-4.79)
Peak 60-min cadence	72 steps	85	39.4 (7.9)	41	41.2 (6.1)	1.709	0.088	0.15	1.83 (0.86-3.87)

Mdn, Median; IQR, Interquartile range; *r*, Rosenthal's *r* effect size; RR (95% CI), Risk ratio (95% confident interval); PC, Percentage. [a] Healthy vs. unhealthy cardiorespiratory fitness profiles (Welk et al., 2011).

Table 5. **Cut-off points and accuracy of the daily step-based recommendations related to having less than 69% of the day in sedentary behavior.**

Step-based index	Cut-off point	%TP	AUC (95% CI)	Se	Sp	*J* max	*P*	*k*
Uncensored total steps	7,773 steps	58.73	0.87 (0.81-0.93)†	0.87	0.70	0.57	0.79	0.57†
Censored total steps	6,836 steps	48.41	0.84 (0.78-0.91)†	0.75	0.78	0.52	0.76	0.52†
Uncensored steps/ min	7.4 steps/ min	49.21	0.88 (0.82-0.94)†	0.79	0.81	0.60	0.80	0.60†
Censored steps/ min	38.8 steps/ min	65.87	0.59 (0.49-0.69)	0.76	0.44	0.21	0.60	0.21*
Minutes 0 steps/ min	652.9 min	58.73	0.87 (0.82-0.93)†	0.89	0.71	0.60	0.80	0.60†
Minutes < 5 steps/ min	911.4 min	58.73	0.74 (0.65-0.82)†	0.79	0.62	0.41	0.71	0.41†
Steps < 5 steps/ min	473.6 steps	54.76	0.78 (0.69-0.86)†	0.32	0.22	-0.46	0.27	0.46†
PC minutes 0 steps/ min	51.8%	29.37	0.76 (0.66-0.86)†	0.57	0.98	0.56	0.78	0.56†
PC minutes < 5 steps/ min	74.7%	30.16	0.77 (0.67-0.87)†	0.60	1.00	0.60	0.80	0.60†
PC steps < 5 steps/ min	5.6%	50.79	0.65 (0.55-0.76)*	0.63	0.62	0.25	0.63	0.25
Minutes 0 steps/ min (bouts)	321.1 min	46.03	0.89 (0.83-0.94)†	0.78	0.86	0.63	0.82	0.64†
Minutes < 5 steps/ min (bouts)	737.2 min	59.52	0.81 (0.74-0.89)†	0.84	0.65	0.49	0.75	0.49†
PC minutes 0 steps/ min (bouts)	28.3%	56.35	0.91 (0.87-0.96)†	0.92	0.79	0.71	0.86	0.71†
PC minutes < 5 steps/min (bouts)	62.4%	51.59	0.96 (0.93-0.99)†	0.90	0.87	0.78	0.89	0.78†
Steps bottom 240 min	0.9 steps	1.59	0.52 (0.42-0.62)	0.03	1.00	0.03	0.52	0.03
Steps bottom 360 min	0.5 steps	13.49	0.62 (0.52-0.72)*	0.25	0.98	0.24	0.62	0.24†
Steps bottom 480 min	0.2 steps	41.27	0.75 (0.66-0.84)†	0.65	0.83	0.48	0.74	0.48†
Steps bottom 600 min	28.4 steps	46.03	0.83 (0.75-0.90)†	0.73	0.81	0.54	0.77	0.54†

%TP, Percentage of total positive cases according to the specified cut-off point; AUC (95% CI), Area Under the Curve (95% confident interval); Se, Sensitivity; Sp, Specificity; *J* max, Youden's index; *P*, Percentage of agreement; *k*, Kappa coefficient; PC, Percentage. * $p < 0.05$, ‡ $p < 0.01$ and † $p < 0.001$.

censored total daily steps) to (hypothetically) make them more comparable to the output of the consumer-wearable activity monitors (see limitations of the present study). In line with the present study (a threshold equal to 8,606 steps/ day, i.e., 2,505 steps less than with the uncensored total steps), Adams et al. (2013) found that censored total daily steps cut-off points have 2,500 steps less. Therefore, for consumer-wearable step-based monitors, among adolescents at least 9,000 steps per day should be recommended.

Regarding the steps cadences, among the analysed rates, the results with the variables ≥ 65 steps/ min (threshold = 5,684 steps) and peak 1-min cadence (threshold = 124 steps) showed the highest accuracy for classifying adolescents as meeting or not meeting the MVPA recommendation. As far as we know, the present study is the first one that establishes and compares the accuracy of daily steps cadence cut-off points related to the MVPA recommendation in adolescents. Although previous laboratory-based studies showed wide variability in the cadence related to moderate PA in young people, outcomes tended to be higher ranging from about 90 to 150 steps/ min (Tudor-Locke et al., 2011; Tudor-Locke et al., 2018). Besides the differences in the samples (e.g., Tudor-Locke et al., 2018, found a lower cadence threshold for adolescents compared with the younger children), differences between devices and methodologies of the studies might also contribute to this variability. For instance, in line with the present study, Barreira et al. (2012) in a descriptive study with a large sample of children aged 6-19 years found that in free-living conditions it is not common to accumulate much time in high cadences (e.g., time accumulated during the day in ≥ 100 steps/ min was about 11 min, i.e., 1.3% of the wear time). On the other hand, similarly to the present study, Barreira et al. (2013) found that children aged 8-18 years without any cardiovascular disease risk factor had higher peak cadences than those with one and/ or two-three risk factors (e.g., peak 1-min cadence = 120 steps/ min, being similar to the 124 steps/ min threshold found in the present study).

Nowadays public health guidelines also recommend that adolescents should minimize the time they spend in SB every day (Stamatakis et al. 2018). When the conception of SB is adopted as simply "any behavior characterized by low energy expenditure requiring ≤ 1.5 METs" (i.e., independently of the individual's posture) (see Table 1 in Tremblay et al., 2017), relatively few (or no) steps are taken during SB (Wong et al., 2011). Therefore, a low number of total daily steps also implies that adolescents have spent the most time on SB (Tudor-Locke et al., 2013). In this line, the present study showed that the daily step-based recommendations with the total daily steps had an adequate accuracy associated with the SB criterion (threshold for uncensored total daily steps = 7,773 steps/ day, threshold for censored total daily steps = 6,836 steps/ day). Similarly to the present study, 7,000 steps/ day has been commonly used in pediatric literature (Tudor-Locke et al., 2013). Regarding the cadence-based steps indexes, the results with the cadence of 0 steps/ min, < 5 steps/ min and steps bottom 600 min showed the highest accuracy for classifying adolescents as meeting or not meeting the SB criterion. However, to our knowledge today there are no previous topic-related research studies to compare with.

A secondary objective was to compare the VO_2max levels between adolescents who met and did not meet the daily step-based recommendations. In line with Parra Saldías et al. (2018), in the present study adolescents that met the daily step-based recommendations related to MVPA had healthier cardiorespiratory fitness levels than those that did not meet them. Additionally, in the present study the RR results showed that adolescents who met a favorable combination of step-based recommendations related to both MVPA and SB thresholds had a higher probability of having a healthy cardiorespiratory fitness profile than those who did not meet either of them or only the one related to MVPA. In line with the present study, Martinez-Gomez et al. (2011) and Santos et al. (2014) found that adolescents classified as high active/low sedentary were

Table 6. Comparison of estimated maximum oxygen uptake levels (ml/ kg/ min) between adolescents who met and did not meet the daily step-based recommendations related to having less than 69% of the day in sedentary behavior.

Step-based index	Cut-off point	Not meeting		Meeting		Mann-Whitney U test			RR (95% CI)[a]
		n	Mdn (IQR)	*n*	Mdn (IQR)	*Z*	*p*	*r*	
Uncensored total steps	7,773 steps	52	39.0 (7.9)	74	41.1 (8.1)	1,213	0.225	0.11	1.89 (0.91-3.92)
Censored total steps	6,836 steps	65	38.5 (7.9)	61	41.1 (7.6)	1.614	0.107	0.14	1.77 (0.87-3.60)
Uncensored steps/ min	7.4 steps/ min	64	38.5 (7.9)	62	41.1 (8.4)	2.093	0.036	0.19	1.90 (0.93-3.88)
Censored steps/ min	38.8 steps/ min	43	39.4 (7.9)	83	41.1 (8.9)	0.648	0.494	0.06	1.29 (0.61-2.73)
Minutes 0 steps/ min	652.9 min	52	41.1 (7.9)	74	41.1 (7.9)	0.276	0.783	0.02	1.26 (0.61-2.57)
Minutes < 5 steps/ min	911.4 min	52	41.1 (7.9)	74	41.1 (7.9)	0.736	0.445	0.07	1.10 (0.54-2.25)
Steps < 5 steps/ min	473.6 steps	57	41.1 (8.1)	69	41.1 (7.9)	1.148	0.251	0.10	0.59 (0.29-1.19)
PC minutes 0 steps/ min	51.8%	89	40.3 (7.9)	37	41.1 (7.6)	0.903	0.367	0.08	1.82 (0.84-3.94)
PC minutes < 5 steps/ min	74.7%	88	39.4 (7.9)	38	41.1 (7.3)	1.147	0.251	0.10	1.68 (0.78-3.62)
PC steps < 5 steps/ min	5.6%	62	39.0 (7.9)	64	41.1 (7.8)	1.506	0.132	0.13	1.49 (0.73-3.02)
Minutes 0 steps/ min (bouts)	321.1 min	68	41.1 (7.9)	58	41.1 (7.9)	0.376	0.707	0.03	1.42 (0.70-2.88)
Minutes < 5 steps/ min (bouts)	737.2 min	51	41.1 (8.9)	75	40.3 (7.9)	1.100	0.271	0.10	1.04 (0.51-2.12)
PC minutes 0 steps/ min (bouts)	28.3%	55	41.1 (7.9)	71	41.1 (7.0)	0.326	0.745	0.03	1.49 (0.73-3.04)
PC minutes <5 steps/min (bouts)	62.4%	61	41.1 (7.9)	65	41.1 (7.9)	0.397	0.692	0.04	1.23 (0.61-2.50)
Steps bottom 240 min	0.9 steps	124	41.1. (7.9)	2	40.8 (-)	-	-	-	-
Steps bottom 360 min	0.5 steps	109	41.1 (7.9)	17	41.1 (8.0)	0.283	0.777	0.03	1.17 (0.42-3.27)
Steps bottom 480 min	0.2 steps	74	39.4 (7.9)	52	41.1 (7.8)	1.007	0.314	0.09	1.77 (0.87-3.64)
Steps bottom 600 min	28.4 steps	68	40.3 (7.9)	58	41.1 (8.1)	0.280	0.780	0.02	1.42 (0.70-2.88)

Mdn, Median; IQR, Interquartile range; *r*, Rosenthal's *r* effect size; RR (95% CI), Risk ratio (95% confident interval); PC, Percentage. [a] Healthy vs. unhealthy cardiorespiratory fitness profiles (Welk et al., 2011).

more likely to have a healthier cardiorespiratory fitness level compared with those from the low-active/high-sedentary group.

Regarding the strengths of the present study, it is worth highlighting that it is the first one that extensively establishes and compares the accuracy of cut-off points of many daily step-based indexes related to MVPA and SB in adolescents. Additionally, as far as we know it is also the first study that establishes and compares the accuracy of cut-off points of daily step-based indexes related to SB in adolescents, which has been pointed out as an important gap in the research related to step-based recommendations in young people (Tudor-Locke et al., 2013). Finally, since meeting both MVPA and SB criteria is considered better than only achieving the 60 min of MVPA (Santos et al., 2014), the proposed step-based recommendations take into account the four possible profiles (i.e., high active/ low sedentary, high active/ high sedentary, low active/ low sedentary, and low active/ high sedentary). Therefore, since the use of consumer-wearable step-based monitors represents the most plausible instrument in public health (Tudor-Locke et al., 2011), the present study is an important advance in the area of objectively assessing and positively promoting adolescents' daily MVPA and SB levels.

As regards the limitations of this study, one weakness was associated with the relatively low number of participants. For instance, results with small-sized samples are less generalizable than with larger samples, boys and girls could not be examined separately or a cross-validation analysis with a subsample could not be performed. Additionally, the present study was conducted with adolescents from a specific area in Chile (i.e., a middle-high-to-high socioeconomic status urban area situated in the city of Santiago) and, thus, this would limit the generalization of the obtained outcomes to the particular studied population and context. Although accelerometry represents a great advance in the monitoring of people's habitual PA and SB levels, another limitation lies in the fact that today there is no strong evidence-based consensus about many methodological decisions (e.g., non-wear period definition, minimum wear time per day or minimum days of valid wear time) (Migueles et al. 2017). According to previous related studies accomplished with adolescents (Adams et al., 2013; Tudor-Locke et al., 2010), in the present study accelerometer-measured total steps were adjusted (i.e., censored total steps) in order to establish step-based cut-off points which would be more comparable to consumer-wearable activity monitors output. However, while recent studies have also found that the accelerometer recorded a lower number of steps (Cruz et al., 2017), others found that both were comparable (Lee et al., 2015). Therefore, the correct selection and interpretation of the present step-based recommendations requires the previous knowledge of the comparison between the accelerometer and the particular consumer-wearable activity monitor used. Finally, another limitation is related to the lack today of a strong evidence-based total daily SB recommendation (Stamatakis et al., 2018). To our knowledge Martinez-Gomez et al. (2011) is the only research study that has tried to specify a total daily SB time threshold associated with a health marker in adolescents. Therefore, the step-based thresholds reported in the present study should be considered simply as a first attempt, taking them more like as an exploration of the potential of the step-based variables for translating SB threshold than the cut-off points them-self.

Further research studies should examine the daily step-based thresholds with larger samples that would allow calculating cut-off points separately by sex and their cross-validity. Furthermore, future research studies with adolescents concurrently wearing accelerometers and common used consumer-wearable activity monitors might find a more accurate translation of daily step-based recommendations. Finally, when there is stronger evidence on the total daily SB threshold among adolescents, future revisions of the present step-based recommendations are required.

Table 7. Comparison of estimated maximum oxygen uptake levels (ml/ kg/ min) between adolescents who met and did not meet the daily step-based recommendations related to both achieving at least 60 min per day of MVPA and having less than 69% of the day in SB.

MVPA[a]	SB[a]	Not meeting		Meeting		Mann-Whitney U test			RR (95% CI)[b]
		n	Mdn (IQR)	*n*	Mdn (IQR)	*Z*	*p*	*r*	
Uncensored total steps	Minutes 0 steps/ min	47	41.1 (7.9)	13	41.1 (6.0)	1.442	0.149	0.19	2.82 (0.80-10.01)
Censored total steps	Minutes 0 steps/ min	46	41.1 (7.9)	20	41.6 (7.1)	1.745	0.081	0.21	2.29 (0.79-6.68)
Uncensored total steps	Steps bottom 600 min	61	39.4 (7.6)	11	41.1 (3.7)	1.590	0.112	0.19	3.10 (0.82-11.79)
Censored total steps	Steps bottom 600 min	60	39.4 (7.3)	18	41.6 (4.8)	1.973	0.048	0.22	2.32 (0.80-6.77)
Min ≥ 65 steps/ min	Uncensored total steps	52	39.0 (7.9)	18	43.8 (6.7)	2.769	0.006	0.33	4.91 (1.51-15.97)
Min ≥ 65 steps/ min	Censored total steps	65	38.5 (7.9)	18	43.8 (6.7)	2.874	0.004	0.32	4.44 (1.41-14.00)
Min ≥ 65 steps/ min	Minutes 0 steps/ min	46	41.1 (7.9)	12	42.5 (4.6)	1.751	0.079	0.23	3.75 (0.98-14.39)
Min ≥ 65 steps/ min	Steps bottom 600 min	60	39.4 (7.3)	10	42.5 (4.0)	1.926	0.054	0.23	4.33 (1.01-18.53)
Steps ≥ 65 steps/ min	Uncensored total steps	52	39.0 (7.9)	20	43.8 (6.4)	2.748	0.006	0.32	4.41 (1.45-13.43)
Steps ≥ 65 steps/ min	Censored total steps	65	38.5 (7.9)	20	43.8 (6.4)	2.866	0.004	0.31	3.99 (1.35-11.75)
Steps ≥ 65 steps/ min	Minutes 0 steps/ min	45	41.1 (7.9)	13	43.8 (5.1)	1.949	0.050	0.26	4.08 (1.08-15.37)
Steps ≥ 65 steps/ min	Steps bottom 600 min	59	39.4 (7.4)	11	43.8 (4.9)	2.176	0.030	0.26	4.83 (1.16-20.16)
Peak 1-min cadence	Uncensored total steps	45	38.5 (6.2)	36	42.1 (6.3)	3.379	0.001	0.38	4.32 (1.69-11.07)
Peak 1-min cadence	Censored total steps	55	38.5 (6.2)	33	42.1 (7.2)	3.446	0.001	0.37	3.62 (1.46-9.00)
Peak 1-min cadence	Minutes 0 steps/ min	37	39.4 (6.6)	28	42.1 (4.9)	2.628	0.009	0.33	4.26 (1.49-12.11)
Peak 1-min cadence	Steps bottom 600 min	47	38.5 (6.2)	22	42.9 (4.2)	3.198	0.001	0.39	5.05 (1.69-15.08)

MVPA, Moderate-to-vigorous physical activity; SB, Sedentary behavior; Mdn, Median; IQR, Interquartile range; r, Rosenthal's r effect size; RR (95% CI), Risk ratio (95% confident interval). [a] The step-based cut-off points used are those reported in the Tables 4 and 6; b Healthy vs. unhealthy cardiorespiratory fitness profiles (Welk et al., 2011).

Conclusion

Total daily step-based recommendations are preferable to cadence-based steps because they are not only simpler but also more accurate for classifying adolescents as meeting or not meeting the MVPA recommendation. A threshold of total daily steps ≥ 11,111 steps/ day seems to be the most appropriate to classify adolescents as physically active. Daily step-based thresholds represent a promising way to translate a total daily SB criterion. However, due to the lack today of a strong evidence-based SB threshold, the step-based recommendations reported in the present study should be considered simply as a first attempt. Adolescents who met a favorable combination of step-based recommendations related to both MVPA and SB criteria had a higher probability of having a healthy cardiorespiratory fitness profile than those who did not meet either of them or only the one related to MVPA. The present study significantly contributes to the evidence-based recommendations on how many daily steps are enough and too few in adolescents. This knowledge may help policy-makers to provide accurate daily step-based recommendations that would simplify MVPA and SB thresholds for adolescents.

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Key points

- Total daily step-based recommendations are preferable than for those with cadence-based steps because they are not only simpler but also more accurate for classifying adolescents as physically active and inactive.
- A threshold of total daily steps ≥ 11,111 steps/ day seems to be the most appropriate to distinguish adolescents that meet the physical activity recommendation among adolescents.
- Daily step-based recommendations represent a promising way to translate a total daily sedentary behavior threshold among adolescents.
- Adolescents who met a favorable combination of step-based recommendations related to both physical activity and sedentary behavior thresholds had a higher probability of having a healthy cardiorespiratory fitness profile than those who did not meet either of them or only the one related to physical activity.

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