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PHYSICAL ACTIVITY, HEALTH AND EXERCISE

A comparison of the utility of different step-indices to translate the physical activity recommendation in adolescents

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ABSTRACT

Previous studies translating the daily moderate-to-vigorous physical activity (MVPA) recommendation of total steps/day among adolescents are inconsistent, and those with cadence-based steps are scarce. The main purpose was to compare the accuracy of different daily steps index-based cut-points related to the daily 60 minutes of MVPA recommendation measured by a waist-worn accelerometer for adolescents. Following a cross-sectional design, 428 Spanish adolescents (final sample 351, 50.4% males), aged 13–16 years old, wore an ActiGraph GT3X/+ accelerometer (reference standard = MVPA; index tests = total steps/day, average steps/min and peak 1-min cadence) on the right hip for eight consecutive days. 32.5% of the adolescents met the daily MVPA recommendation. The multiple ROC curve comparisons showed that the accuracy of the daily total step-based recommendation (AUC = 0.97) was statistically higher than for those with the steps/min (AUC = 0.90) and peak 1-min cadence (AUC = 0.58) (p < 0.001). The 10,000-step-per-day cut-point (k= 0.59–0.83) showed highest accuracy values than the 12,000 steps/day (k= 0.20–0.32). Daily total step-based recommendations are more accurate than those with steps/min and peak 1-min cadence for classifying adolescents as being physically active or inactive. A 10,000-step-per-day target is simple and accurate for both male and female adolescents.

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KEYWORDS
Activity trackers; steps per day; step counts; walking cadence; thresholds; youth

Introduction

The World Health Organization (2010) recommends that adolescents should achieve at least 60 minutes per day of moderate-to-vigorous physical activity (MVPA). For instance, the achievement of at least 60 minutes per day of MVPA among adolescents is favourably related to several health markers such as cardiometabolic biomarkers, body composition and physical fitness (Poitras et al., 2016). However, since most adolescents and their parents have a low ability to correctly identify daily MVPA-intensity activities(Crossley et al., 2019), the MVPA recommendation may not be easily understood by either group (Tudor-Locke et al., 2011). In this context, since worldwide about eight out of ten adolescents do not meet the daily MVPA recommendation (World Health Organization, 2014), a current global action plan is to reduce by 15% the number of adolescents who are physically inactive by 2030 (World Health Organization, 2018).

Today there is a growing interest in establishing daily step-based recommendations related to the 60 minutes per day of MVPA among adolescents (Tudor-Locke et al., 2011; 2018). Besides having the advantage of being very simple to understand (Tudor-Locke et al., 2011), steps per day is the main physical activity (PA) output of the consumer-wearable activity trackers, which have become very popular during the last decade (Althof et al., 2017). Unfortunately, the outcomes of previous studies translating the daily MVPA recommendation to steps per day among adolescents are inconsistent, ranging from 7,500 to 14,000 step-per-day cut-points (Adams et al., 2009; 2013; Benítez-Porres et al., 2016; Colley et al., 2012; Fontana et al., 2015; Mayorga-Vega et al., 2019). In line with this scenario, the two topic-related reviews do not agree on the daily total step-based recommendations for adolescents (Da Silva et al., 2015; Tudor-Locke et al., 2011). Besides differences in setting and several methodological issues (Bossuy et al., 2015), the step-based cut-point inconsistency could be due to the fact that steps per day do not assess intensity, which is an essential dimension of the MVPA recommendation (Tudor-Locke et al., 2018).

Currently, many cadence-based steps outputs have been proposed, such as daily average steps/min or peak 1-min cadence, whose translation to the MVPA recommendation should also be examined (Mayorga-Vega et al., 2019). To our knowledge, to date only Mayorga-Vega et al. (2019) examined the translation of the MVPA recommendation to steps/min and peak 1-min cadence in adolescents. Unfortunately, the above-mentioned study has some major limitations such as not comparing the accuracy by any statistical method or collecting data in 1-min *epochs*. Therefore, besides drastically affecting the MVPA standard (Aibar et al., 2014), their outcomes are related to steps accumulation within an *epoch* of time of 1 min and not true cadence (Stansfield et al., 2015). On the other hand, after

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Supplemental data for this article can be accessed online here.

the development of criterion-referenced standards, the cross-validation of these cut-points using additional samples should also be examined (Zhu et al., 2011). However, although a few previous studies examined the cross-validity of daily total step-based cut-points (Adams et al., 2013; Colley et al., 2012; Parra Saldías et al., 2018), as far as we know no previous study has cross-validated the cadence step-based recommendations. Finally, despite the differences in PA prevalence and patterns between genders (Mayorga-Vega et al., 2017), most of the previous studies were carried out with males and females together. Consequently, studies taking into account all the above-mentioned issues are necessary.

Aims

The main aim of the present study was to compare the accuracy of different daily steps index-based cut-points related to the daily 60 minutes of MVPA recommendation measured by a waist-worn accelerometer in adolescents. The secondary purposes of this study were the following: (a) to examine potential differences between male and female adolescents in the comparison of the accuracy of different daily steps index-based cut-points, and (b) to compare the cross-validity of daily step-based cut-points established in both the present and previous studies in adolescents. The null hypothesis was that the accuracy of different daily steps index-based cut-points measured by a waist-worn accelerometer in adolescents was equal.

Material and methods

Participants

The present diagnostic accuracy study followed a cross-sectional design. The study is reported according to the STARD guidelines (Bossuy et al., 2015). The protocol of the present study was approved by the Ethical Committee for Human Studies at the University of Granada and University of Málaga. Data were collected at two different schools in the same period of the year. Recruitment was carried out from November to December of 2016 (sample A) and 2018 (sample B), and data collection from January to February of 2017 (sample A) and 2019 (sample B). Permission to conduct the study was requested and obtained in two state high schools chosen by convenience. Then, students and their legal guardians were fully informed about the project. Adolescents' signed written informed assents and their legal guardians signed written informed consents were obtained before taking part in the study.

All the students enrolled in the second and fourth grade (i.e. 13–16 years old; sample A) and the second and third grade (i.e. 13–15 years old; sample B) were invited to participate (i.e. grades where the schools' approvals were obtained). The high schools of the samples A and B were located in the urban and metropolitan areas, respectively, of Granada (Andalucía, Spain). All the adolescents' families had a middle socioeconomic level. The inclusion criteria were: (a) being enrolled in the grades where the schools' approvals were obtained; (b) being free of any health disorder that would make them unable to engage in PA normally; (c) presenting the corresponding signed written informed assent by the adolescents themselves, and (d) presenting the corresponding signed written informed consent by their legal guardians. The exclusion criterion was not having at least one day with 600 minutes or more of valid wear time.

Measures

Demographic characteristics. Adolescents' gender and age information was obtained from the school reports.

Anthropometric. Adolescents' body mass and height were first measured following the International Standards for Anthropometric Assessment (Stewart et al., 2011). Adolescents' body mass and height were measured in shorts, T-shirts, and barefoot. For the body mass measure, the adolescents stood in the centre of the scale (Seca, Ltd., Hamburg, Germany; accuracy = 0.1 kg) without support and with the weight distributed evenly on both feet. For the body height assessment, adolescents stood with the feet together with the heels, buttocks and upper part of the back touching the stadiometer (Holtain Ltd., Crymmych, Pembs, United Kingdom; accuracy = 0.1 cm), and with the head placed in the Frankfort plane. The average of two measurements of both body mass and height was calculated. Then, the body mass index was calculated as body mass divided by body height squared (kg/m^2). Finally, adolescents' body weight status was categorized by the body mass index cut-points as overweight/obesity (i.e. gender- and age-adjusted cut-point values equal to or higher than the equivalent value of 25 kg/m^2 at the age of 18 years) or non-overweight/obesity (i.e. lower than the equivalent cut-point values of 25 kg/m^2 at the age of 18 years) (Cole et al., 2000). Body mass index has shown high validity for assessing body composition among adolescents (Castro-Piñero et al., 2010).

Accelerometry. Adolescents' daily PA levels were objectively determined by GT3X/+ accelerometers (ActiGraph, LLC, Pensacola, FL, USA). Specifically, the following daily PA measures were retrieved: (1) MVPA (i.e. total time in minutes accumulated at ≥ 2,296 *counts*/min) (Evenson et al., 2008; Trost et al., 2011) in the vertical axis during a day); (2) steps per day (i.e. total number of steps recorded during a day); (3) steps/min (i.e. steps per day divided by the total number of minutes recorded during the day); and (4) peak 1-min cadence (i.e. steps accumulated during the highest single minute in a day). ActiGraph accelerometer scores have shown strong evidence supporting criterion-related validity for assessing MVPA and steps levels among adolescents (Arvidsson et al., 2011; Trost et al., 2011).

Accelerometers were adjusted on the adolescents' waist (right hip) and they were instructed to wear them for eight consecutive days from waking to bedtime. Initializing, downloading, wear time validation and scoring were performed using the ActiLife Lifestyle Monitoring System Software version 6.13.4 (ActiGraph, LLC, Pensacola, FL, USA). Accelerometers were initialized with a sample ration of 30 Hz (Evenson et al., 2008; Trost et al., 2011). Since adolescents' PA patterns are characterized by short bursts of quickly changing activity, data download was carried out with one-second *epochs*

(Migueles et al., 2017). To avoid potential biases due to adolescents' reactivity, the first monitored day was considered as a familiarization day (i.e. the device was initialized on the next day; i.e. data were collected for 7 days) (Shephard & Tudor-Locke, 2016). Valid wear time was set as equal to or higher than 600 minutes per day (Migueles et al., 2017) with non-wear periods set as 60 minutes or more of consecutive zero-count *epochs* with up to 2 min spike tolerance (Oliver et al., 2011). Regarding the data scoring, the time engaged in MVPA was calculated by the cut-point equal to or higher than 2,296 *counts*/min (Evenson et al., 2008). According to the cross-validation study performed by Trost et al. (2011), this cut-point has demonstrated the best evidence supporting score validity for assessing MVPA with one-second *epochs* among adolescents. Steps were assessed by the within-instrument processing of the number of cycles in the accelerometer signal or *cycle counts*.

Afterwards, the adolescents' daily PA levels were calculated as the mean value of the valid days. Then, adolescents' daily MVPA was categorized as meeting or not meeting the recommendation of achieving at least 60 minutes per day of MVPA (reference standard) (World Health Organization, 2010). Finally, adolescents' daily steps were categorized as achieving or not achieving the daily steps cut-points established in both the present study and in previous empirical studies conducted with adolescents (index tests) (see Tables 2 and 3).

Procedure

Data collection was carried out during the physical education class time by the same researchers, instruments and protocols. Due to human and material resources restrictions, data were collected in three waves at each school. Accelerometers were adjusted by the researchers on adolescents' waist (right hip) using an elastic waistband. Adolescents were instructed to wear the accelerometer for eight consecutive days from waking to bedtime. During the waking time, adolescents were urged to maintain their habitual PA levels and they were asked to take the accelerometer off only when they engaged in aquatic activities or took a bath/shower. Information regarding the correct wearing of the accelerometer was explained prior to the initial attachment. This information was provided to the adolescents and parents in written form to ensure they could check and correct the attachment on a regular basis. In the next week, accelerometers were collected and anthropometric measurements (i.e. body mass and height) were taken.

Statistical analysis

Descriptive statistics (mean ± standard deviation or percentage) for all the variables of the analysed participants were first calculated. Then, the one-way analyses of variance (ANOVA) (continuous variables) and the chi-squared test (categorical variables) were conducted to examine potential differences in terms of general characteristics between males and females and samples A and B. Afterwards, receiver operating characteristic (ROC) curve analyses were used to estimate the accuracy of the daily step-based indexes related to achieving or not achieving the recommended 60 minutes per day of MVPA (Bossuy et al., 2015). The parameters were set as follows: (a) the nonparametric method for curve fitting; (b) the DeLong method for confidence interval, and (c) the Youden method for the optimal cut-point (Goksuluk et al., 2016). The areas under the ROC curves (AUC) and the partial AUCs (with values range from 0.80 to 1.00) were calculated (Goksuluk et al., 2016). Moreover, sensitivity and specificity were calculated to provide the test accuracy in terms of adolescents' population (Mallet et al., 2012). Sensitivity was referred to as the probability of correctly detecting adolescents who met the daily MVPA recommendation, and specificity referred to those who did not meet it. Positive predictive value was estimated to examine the probability that a particular adolescent with a given positive test result met the daily MVPA recommendation, whereas the negative predictive value was estimated to detect those adolescents with a given negative test result (Mallet et al., 2012). Positive and negative likelihood ratios were used to calculate the role of a test result in changing an estimate of the probability of meeting the daily MVPA recommendation in a particular adolescent (Mallet et al., 2012). Proportion of agreement (P) and Kappa coefficient (k) were calculated to examine the agreement between the step-based indexes and the reference standard (Hernaez, 2015). Finally, multiple ROC curve comparisons were performed using the Bonferroni method (Goksuluk et al., 2016).

Since imputation of the missing data requires strong assumptions that are hard to justify (Streiner, 2008), "complete case" analyses including only those whose all the outcomes were known were used (i.e. 351 participants). A priori sample size calculation was estimated with the method of comparison of the two tests. The parameters were set as follows: Type I error = 0.05, Power = 0.80, AUC for the first/second test under null hypothesis = 0.50, AUC for the first/second test under alternative hypothesis = 0.90/0.70 (based on Mayorga-Vega et al. (2019)), and allocation ratio = 4 (based on World Health Organization (2014)). A final sample size of 180 adolescents was estimated. All statistical analyses were performed using the Web-tool easyROC version 1.3.1 (Goksuluk et al., 2016), except for P and k, which were performed using the SPSS version 25.0 for Windows (IBM® SPSS® Statistics). The statistical significance level was set at $p < 0.05$.

Results

General characteristics

Figure 1 shows the flow diagram of the participants through the study. Since there were several possibilities combining different samples and step-based variables, as an example, in the flow diagram the index test data are reported only for steps per day with the whole sample. An initial sample of 428 adolescents (221/207 and 51.6/48.4% males/females; sample A = 165, 38.6%, 88/77 and 53.3/46.7% males/females; sample B = 263, 61.4%, 133/130 and 50.6/49.4% males/females) agreed to participate and met the inclusion criteria. However, since 77 adolescents (18.0%; 47/30 and 11.0/7.0% males/females; sample A = 25, 5.8%, 17/8 and 4.0/1.9% males/females; sample B = 52, 12.1%, 30/22 and 7.0/

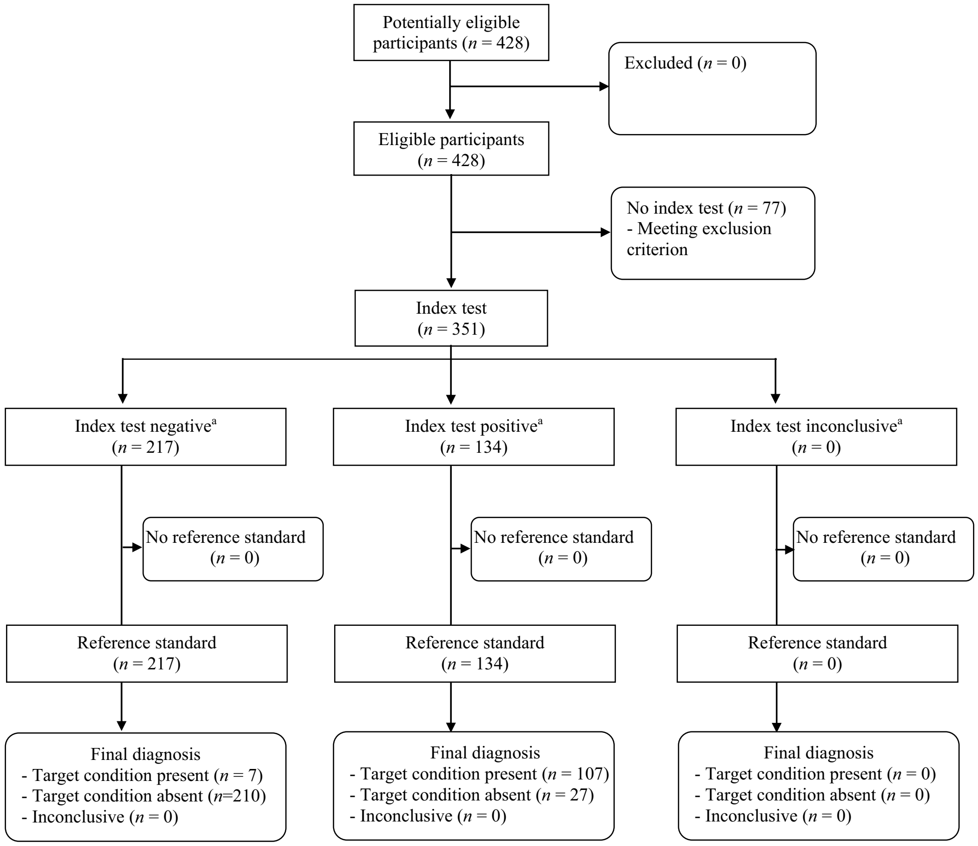

Figure 1. Flow diagram of the participants through the study. Since there were several possibilities combining different samples and step-based variables, as an example, in the flow diagram the index test data are reported only for steps per day with the whole sample.

5.1% males/females) met at least one exclusion criterion, the final sample consisted of 351 participants (82.0%; 174/177 and 40.7/41.4% males/females; sample A = 140, 32.7%, 71/69 and 16.6/16.1% males/females; sample B = 211, 49.3%, 103/108 and 24.1/25.2% males/females) (i.e. non-compliance rate, total sample = 18.0%; males = 21.3%; females = 24.2%; sample A = 15.2%; sample B = 19.8%). Table 1 shows the general characteristics of the included participants.

Accuracy of daily step-based cut-points related to the recommended moderate-to-vigorous physical activity

Figure 2 shows the ROC curve plot for the whole sample and the Supplemental Figure 1 shows the ROC curve plots for males, females, sample A and sample B separately. Table 2 shows the accuracy of daily step-based recommendations related to achieving 60 minutes per day of MVPA. A total of 32.5% (males = 39.1%; females = 26.0%; sample A = 39.3%; sample B = 28.0%) of the adolescents met the daily MVPA recommendation. The multiple ROC curve comparisons with the Bonferroni method showed that the accuracy of the daily total step-based recommendation was statistically significantly higher than for those with the steps/min and peak 1-min cadence (p < 0.001). Additionally, the accuracy of the daily steps/min-based recommendation was statistically significantly higher than for those with the peak 1-min cadence (p < 0.001). The same outcomes were found among males, females, sample A and sample B separately (except for sample B in which between the accuracy of steps/day- and steps/min-based cut-points statistically significant differences were not found, p > 0.05).

Cross-validity of daily step-based cut-points related to the recommended moderate-to-vigorous physical activity

Table 3 shows the cross-validity of daily step-based recommendations related to achieving 60 minutes per day of MVPA. A total of 3.6–50.0% (median = 18.6%; sample A) and 2.4–44.1% (median = 12.3%; sample B) of the adolescents met the daily total step-based recommendations; 0.0–44.3% (sample A) and 0.0–46.4% (sample B) met the daily steps/min-based recommendations; and 55.0–100.0% (sample A) and 34.1–100.0% (sample B) met the peak 1-min cadence-based recommendations. Together with the daily total step-based thresholds obtained in the present study (i.e. 9,070 and 8,521 steps/day), the 8,606 and 9,701 step-per-day cut-points showed the highest accuracy values (e.g. sample A: P = 0.94, k = 0.86–0.88; sample B: P = 0.88–0.89, k = 0.71–0.72). When the most widely proposed daily step-based recommendations among adolescents was compared (i.e. 10,000 and 12,000 steps), the 10,000-step-per-day cut-point showed the highest accuracy values. Regarding the steps/min- and peak 1-min cadence-based recommendations, the cut-points obtained in the present

Table 1. General characteristics of the analysed participants.

	Total	Males	Females	Sample A	Sample B
	(*N* = 351, 100.0%)	(*n*= 174, 49.6%)	(*n* = 177, 50.4%)	(*n* = 140, 39.9%)	(*n* = 211, 60.1%)
Age (years)[a]	14.0 (0.9)	14.1 (1.0)	13.9 (0.9)	14.0 (1.1)	14.0 (0.9)
Gender (females/males)[b]	177/174	0/174	177/0	69/71	108/103
Gender (females/males)[c]	50.4/49.6	0.0/100.0	100.0/0.0	49.3/50.7	51.2/48.8
Body mass (kg)[a]	58.1 (11.8)	60.3 (12.5)	55.9 (10.7)†	57.3 (10.3)	58.6 (12.7)
Body height (cm)[a]	163.5 (8.0)	167.2 (8.1)	159.8 (6.1)†	162.8 (8.0)	163.9 (8.0)
Body mass index (kg/m^2)[a]	21.7 (3.7)	21.5 (3.8)	21.8 (3.6)	21.6 (3.2)	21.7 (4.0)
Overweight-obesity (no/yes)[b]	259/92	127/47	133/44	105/35	154/57
Overweight-obesity (no/yes)[c]	73.9/26.1	72.8/27.2	75.0/25.0	75.0/25.0	73.2/26.8
Daily MVPA (min)[a]	51.7 (21.0)	55.9 (21.6)	47.5 (19.5)†	56.0 (21.4)	48.8 (20.3)‡
≥ 60 minutes daily MVPA (no/yes)[b]	237/114	106/68	131/46	85/55	152/59
≥ 60 minutes daily MVPA (no/yes)[c]	67.5/32.5	60.9/39.1	74.0/26.0‡	60.7/39.3	72.0/28.0*
Daily total steps[a]	7,981.0 (2,661.2)	8,414.0 (2,796.4)	7,555.3 (2,455.4)‡	8346.1 (2,734.7)	7,738.8 (2,589.5)*
Daily steps/min[a]	8.8 (3.3)	9.4 (3.5)	8.2 (3.0)*	8.8 (3.5)	8.8 (3.2)
Daily peak 1-min cadence[a]	220.7 (18.2)	220.8 (19.5)	220.7 (16.8)	223.8 (18.6)	218.7 (17.6)*

Data are reported as [a]mean (standard deviation), [b]number or [c]percentage; MVPA = Moderate-to-vigorous physical activity.
* $p < 0.05$, ‡ $p < 0.01$ and † $p < 0.001$: Comparison between males-females and samples A-B with the one-way analysis of variance for continuous variables and the chi-squared test for categorical variables.

study (i.e. 9.4–9.9 steps/min and 223–230 steps/min, respectively) showed the highest accuracy values.

Discussion

The present study compared the accuracy of different daily steps index-based cut-points related to the daily 60 minutes of MVPA recommendation measured by a waist-worn accelerometer in adolescents, as well as it examined potential differences between males and females. Moreover, this study compared the cross-validity of daily step-based cut-points established in both the present and previous studies in adolescents. Following a cross-sectional design, the outcomes of the present study showed that the accuracy of the daily total step-based recommendation was higher than for those with the steps/min and peak 1-min cadence. Additionally, the accuracy of the daily steps/min-based recommendation was higher than for those with the peak 1-min cadence. There was no difference between males and females. The outcomes also showed that, together with the daily total step-based recommendations proposed in this study (i.e. 8,521 and 9,070 steps/day), the 8,606 (Mayorga-Vega et al., 2019) and 9,701 (Benítez-Porres et al., 2016) step-per-day cut-points showed the highest accuracy values. Finally, when the most widely proposed daily step-based recommendations among adolescents were compared (i.e. 10,000 and 12,000 steps), the accuracy with the 10,000-step-per-day cut-point showed the highest values. Therefore, it was concluded that total step-based recommendations are more accurate than those with cadence-based steps for classifying both male and female adolescents as physically active or inactive. Considering both present and previous evidence, 10,000 steps/day measured by a waist-worn accelerometer seems to

Table 2. Accuracy of daily step-based recommendations related to achieving at least 60 minutes per day of moderate-to-vigorous physical activity.

	Cut-point	TP	%TP	AUC (95% CI)	$PAUC_{Se}$	$PAUC_{Sp}$	Youden	Se	Sp	PPV	NPV	PLR	NLR	*P*	*k*
Total sample (N = 351)															
Total steps	8,521	134	38.2	0.97 (0.96 – 0.99)†	0.94	0.93	0.83	0.95	0.89	0.80	0.97	8.32*	0.06*	0.90	0.79†
Steps/min	9.9	113	32.2	0.90 (0.87 – 0.94)†	0.79	0.83	0.65	0.76	0.89	0.77	0.89	6.96*	0.27*	0.85	0.66†
Peak 1-min cadence	230	137	39.0	0.58 (0.51 – 0.64)*	0.52	0.54	0.12	0.48	0.65	0.39	0.72	1.35*	0.81*	0.59	0.12*
Males (*n* = 174)															
Total steps	8,639	79	45.4	0.98 (0.96 – 0.99)†	0.95	0.94	0.85	0.97	0.88	0.84	0.98	7.91*	0.03*	0.91	0.82†
Steps/min	10.9	54	31.0	0.91 (0.87 – 0.96)†	0.78	0.87	0.70	0.74	0.96	0.93	0.85	19.49*	0.28*	0.87	0.72†
Peak 1-min cadence	223	87	50.0	0.61 (0.52 – 0.69)*	0.53	0.54	0.22	0.63	0.59	0.49	0.71	1.52*	0.63*	0.60	0.21‡
Females (*n* = 177)															
Total steps	8,058	67	37.9	0.96 (0.94 – 0.99)†	0.93	0.90	0.81	0.98	0.83	0.67	0.99	5.83*	0.03*	0.87	0.71†
Steps/min	8.9	59	33.3	0.90 (0.84 – 0.95)†	0.80	0.80	0.68	0.85	0.83	0.64	0.94	5.05*	0.18*	0.84	0.61†
Peak 1-min cadence	204	151	85.3	0.54 (0.44 – 0.63)	0.53	0.52	0.08	0.91	0.17	0.28	0.85	1.10*	0.52	0.36	0.05
Sample A (n = 140)															
Total steps	9,070	56	40.0	0.99 (0.98 – 1.00)†	0.98	0.98	0.93	0.96	0.97	0.95	0.98	27.30*	0.04*	0.96	0.93†
Steps/min	9.9	45	32.1	0.91 (0.86 – 0.96)†	0.79	0.85	0.70	0.75	0.95	0.91	0.85	15.84*	0.27*	0.87	0.72†
Peak 1-min cadence	230	65	46.4	0.60 (0.51 – 0.69)*	0.54	0.54	0.16	0.56	0.60	0.48	0.68	1.41	0.73	0.59	0.16
Sample B (n = 211)															
Total steps	8,521	75	35.6	0.95 (0.93 – 0.98)†	0.92	0.88	0.79	0.93	0.86	0.72	0.97	6.75*	0.08*	0.88	0.72†
Steps/min	9.4	82	38.9	0.91 (0.86 – 0.95)†	0.81	0.82	0.68	0.88	0.80	0.63	0.95	4.47*	0.15*	0.82	0.61†
Peak 1-min cadence	223	101	47.9	0.54 (0.45 – 0.63)	0.51	0.52	0.09	0.54	0.55	0.32	0.76	1.29	0.84	0.55	0.07

TP/%TP = Number/percentage of total positive cases according to the specified cut-point; AUC (95% CI) = Area under the curve (95% confident interval); PAUC-Se/Sp = Partial AUC with sensitivity/specificity at 0.80–1.0; Se = Sensitivity; Sp = Specificity; PPV = Positive predictive value; NPV = Negative predictive value; PLR = Positive likelihood ratio; NLR = Negative likelihood ratio; *P* = Proportion of agreement; *k* = Kappa coefficient.
* $p < 0.05$, ‡ $p < 0.01$ and † $p < 0.001$.

Table 3. Cross-validity of daily step-based recommendations related to achieving at least 60 minutes per day of moderate-to-vigorous physical activity.

		Sample A (*n* = 140)							Sample B (*n* = 211)						
Reference	Cut-point (males/females)	TP	%TP	Youden	Se	Sp	*P*	*k*	TP	%TP	Youden	Se	Sp	*P*	*k*
Total steps															
Adams et al. (2009)	9,930	45	32.1	0.82	0.82	1.00	0.93	0.85†	37	17.5	0.53	0.56	0.97	0.86	0.60†
Adams et al. (2009)	11,714	17	12.1	0.31	0.31	1.00	0.73	0.35†	13	6.2	0.20	0.20	0.99	0.77	0.26†
Colley et al. (2012)	12,000	16	11.4	0.29	0.29	1.00	0.72	0.33†	10	4.7	0.15	0.15	0.99	0.76	0.20†
Adams et al. (2013)	11,000/10,500	26	18.6	0.47	0.47	1.00	0.79	0.52†	26	12.3	0.39	0.41	0.99	0.82	0.48†
Adams et al. (2013)	14,000/11,500	5	3.6	0.09	0.09	1.00	0.64	0.11‡	5	2.4	0.06	0.07	0.99	0.73	0.09‡
Adams et al. (2013)	13,000/12,000	9	6.4	0.16	0.16	1.00	0.67	0.19†	8	3.8	0.11	0.12	0.99	0.75	0.15†
Adams et al. (2013)	8,500/7,500	70	50.0	0.79	0.98	0.81	0.88	0.76†	93	44.1	0.75	0.98	0.77	0.83	0.64†
Adams et al. (2013)	11,500/9,000	36	25.7	0.62	0.64	0.99	0.85	0.67†	35	16.6	0.43	0.47	0.95	0.82	0.49†
Adams et al. (2013)	10,500/9,500	40	28.6	0.73	0.73	1.00	0.89	0.76†	42	19.9	0.59	0.63	0.97	0.87	0.65†
Fontana et al. (2015)	12,118	14	10.0	0.25	0.25	1.00	0.71	0.29†	10	4.7	0.15	0.15	0.99	0.76	0.20†
Fontana et al. (2015)	12,118/12,605	12	8.6	0.22	0.22	1.00	0.69	0.25†	9	4.3	0.15	0.15	1.00	0.76	0.21†
Benítez-Porres et al. (2016)	9,701	46	32.9	0.84	0.84	1.00	0.94	0.86†	48	22.7	0.67	0.71	0.96	0.89	0.71†
Mayorga-Vega et al. (2019)	11,111	24	17.1	0.44	0.44	1.00	0.78	0.49†	22	10.4	0.35	0.36	0.99	0.82	0.43†
Mayorga-Vega et al. (2019)	8,606	59	42.1	0.89	0.96	0.93	0.94	0.88†	75	35.5	0.78	0.92	0.86	0.88	0.72†
Tudor-Locke et al. (2011)	10,000	44	31.4	0.80	0.80	1.00	0.92	0.83†	36	17.1	0.52	0.54	0.97	0.85	0.59†
Da Silva et al. (2015)	12,000	16	11.4	0.29	0.29	1.00	0.72	0.33†	10	4.7	0.15	0.15	0.99	0.76	0.20†
Present study	8,521 − 9,070[a]	59	42.1	0.89	0.96	0.93	0.94	0.88†	62	29.4	0.72	0.81	0.91	0.88	0.71†
Steps/min															
Mayorga-Vega et al. (2019)	8.7	62	44.3	0.65	0.84	0.81	0.82	0.63†	98	46.4	0.60	0.90	0.70	0.76	0.50†
Mayorga-Vega et al. (2019)	45.1	0	0.0	0.00	0.00	1.00	0.61	0.00	0	0.0	0.00	0.00	1.00	0.72	0.00
Present study	9.4 − 9.9[a]	50	35.7	0.64	0.75	0.89	0.84	0.65†	68	32.2	0.63	0.78	0.86	0.83	0.61†
Peak 1-min cadence															
Mayorga-Vega et al. (2019)	124	140	100.0	0.00	1.00	0.00	0.39	0.00	211	100.0	0.00	1.00	0.00	0.28	0.00
Present study	223 − 230[a]	77	55.0	0.14	0.64	0.51	0.56	0.13	72	34.1	0.07	0.39	0.68	0.60	0.06

TP/%TP = Number/percentage of total positive cases according to the specified cut-point; Se = Sensitivity; Sp = Specificity; *P* = Proportion of agreement; *k* = Kappa coefficient. [a] Cut-point values proposed for the samples B and A, respectively.
‡ $p < 0.01$ and † $p < 0.001$.

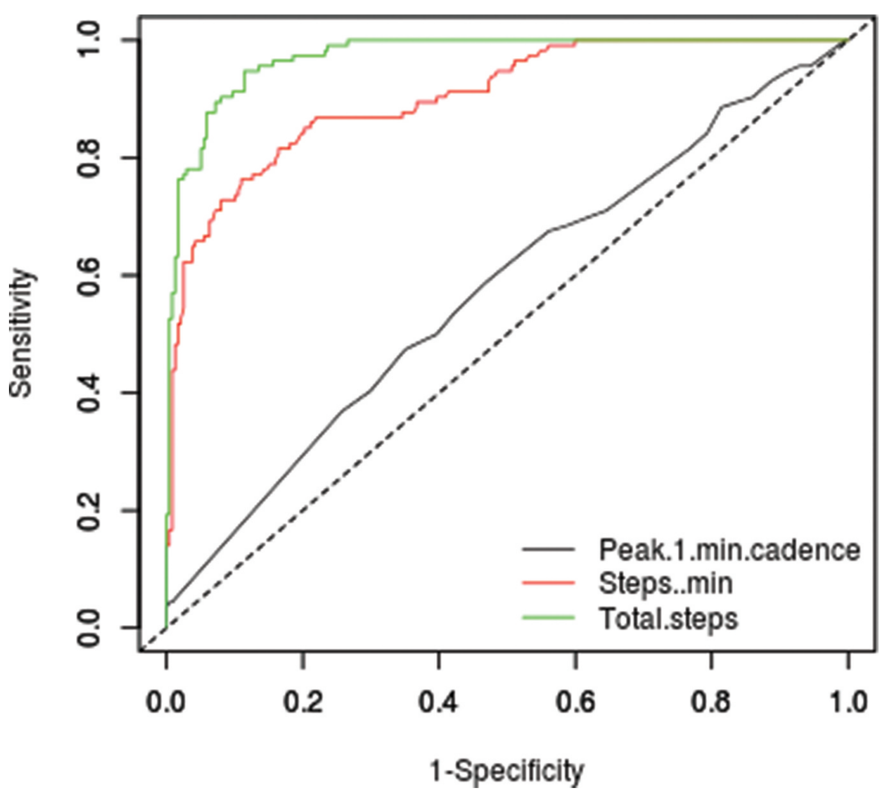

Figure 2. Receiver Operating Characteristic (ROC) curve analyses estimating the accuracy of daily step-based indexes related to achieving or not achieving the recommended 60 minutes per day of moderate-to-vigorous physical activity.

be an adequate cut-point with which to classify both male and female adolescents. Consequently, the null hypothesis that the accuracy of different daily steps index-based cut-points measured by a waist-worn accelerometer in adolescents that was equal was rejected.

To our knowledge, to date only Mayorga-Vega et al. (2019) had examined the translation of the MVPA recommendation to total steps, steps/min and peak 1-min cadence in adolescents. As in the present study, the above-mentioned authors assessed both steps and MVPA by a waist-worn accelerometer. Although Mayorga-Vega et al. (2019) did not compare the accuracy by any statistical method, the accuracy values followed the same tendency as in the present study (e.g. AUC = 0.94, 0.92, and 0.76; P = 0.93, 0.88, and 0.71; k = 0.67, 0.55, and 0.24, for the total steps, steps/min and peak 1-min cadence, respectively). However, separate analyses by genders were not calculated. In line with the findings of the present study, Mayorga-Vega et al. (2019) concluded that total step-based recommendations were preferable to those with cadence-based steps for classifying adolescents as meeting or not meeting the MVPA recommendation.

Regarding the total steps index, the results of the present study showed very high accuracy for translating the MVPA recommendation measured by a waist-worn accelerometer, being similar in males and females. In line with the present study, all the previous studies also found high accuracy of the daily total step-based translation of the MVPA recommendation measured by waist-worn monitors in adolescents (e.g. AUC = 0.80–0.99) (Adams et al., 2009; 2013; Benítez-Porres et al., 2016; Colley et al., 2012; Fontana et al., 2015; Mayorga-Vega et al., 2019). However, the cut-points of previous studies translating the daily MVPA recommendation to steps per day among adolescents have shown a high variability, ranging from 7,500 to 14,000 steps/day (Adams et al., 2009; 2013; Benítez-Porres et al., 2016; Colley et al., 2012; Fontana et al., 2015; Mayorga-Vega et al., 2019). Similarly, a high variability was also found for males (8,500 − 14,000 steps/day) and females (7,500 − 12,605 steps/day) separately (Adams et al., 2013; Fontana et al., 2015). Although the cut-point of the present study was inside the above-mentioned threshold (i.e. 8,501, 8,639 and 8,058 steps/day, respectively), the previous studies with uncensored total steps as in the present study tended to obtain higher daily total steps cut-points, ranging from 9,701 to 14,000 steps/day (Adams et al., 2009; 2013; Benítez-Porres et al., 2016; Colley et al., 2012; Mayorga-Vega et al., 2019); among males (11,000 − 14,000 vs. 8,500 − 11,500 steps/day) and females (10,500 − 12,000 vs. 7,500 − 9,500 steps/day) (Adams et al., 2013). Regarding the steps/min and peak 1-min cadence, although Mayorga-Vega et al. (2019) found a similar cut-point value for steps/min (e.g. AUC = 0.92 vs. 0.90/0.98/0.96; cut-point = 8.8 vs. 9.9/10.9/8.9 steps/min for total/males/females), the value for the peak 1-min cadence was notably different (e.g. AUC = 0.76 vs. 0.58/0.61/0.54; cut-point = 124 vs. 230/223/204 steps for total/males/females). Since the peak 1-min cadence only considers the maximum steps/min value of the day (i.e. steps accumulated during the highest single minute in a day, and not all the data as in the total steps and steps/min), this difference could be due to the fact that the peak 1-min cadence may be more sensitive to any difference in setting or methodological issues. Among other reasons, previous authors collected data in 1-min *epochs* and, thus, their outcomes should be considered as steps accumulation within an *epoch* of time of 1 min and not true cadence (Stansfield et al., 2015).

Sensitivity and specificity are not fixed test properties and, thus, several differences in setting and methodological issues could explain the step-based cut-points' variability(Bossuy et al., 2015). Regarding the setting, for instance, it is well established that the prevalence (i.e. adolescents meeting the MVPA recommendation) affects sensitivity/specificity (Leeflang et al., 2013; Li & Fine, 2011) and, therefore, the step-based cut-point. While in the present study 32.5% of adolescents met the 60 minutes per day of MVPA recommendation, in the previous studies this value ranged between 8.6% and 48.0% (Adams et al., 2009; 2013; Benítez-Porres et al., 2016; Colley et al., 2012; Fontana et al., 2015; Mayorga-Vega et al., 2019); 14.3 and 57.3% and 2.9 and 27.4% for males and females, respectively (Adams et al., 2013; Fontana et al., 2015). In this context, although in the present study the two subsamples followed the same methodological procedures, the prevalence differed in 11.3% (i.e. sample A = 39.3% and sample B = 28.0%), and the total step-based cut-point in 549 steps (i.e. 9,070 and 8,521 steps/day, respectively). In relation to the prevalence, differences in the PA patterns of the samples could also affect the step-based recommendations. For instance, since total daily steps is an indicator of total PA (i.e. light-to-vigorous PA) (Tudor-Locke et al., 2013) and the reference standard recommendation is based on MVPA, the ratio of light PA/MVPA could affect the steps-based cut-points. Additionally, although most of total PA (and, thus, MVPA) is usually performed by many step-based activity modes, such as waking or running (e.g. in the present study the 76.4% and 84.9% of variance in the time in total PA and MVPA, respectively, is explained by total steps), the non-step-based activity modes could also affect the step-based recommendations. In this context, since differences in PA patterns between genders have been found (Mayorga-Vega et al., 2017), in the present study the total steps cut-point also differed between males and females in 581 steps (i.e. 8,639 and 8,058 steps/day, respectively).

Methodological issues could also explain the variability of the step-based thresholds (Bossuy et al., 2015). Regarding the PA reference standard, although accelerometry represents a great advance in the monitoring of adolescents' daily PA levels, today there is no strong evidence-based consensus about many methodological decisions (e.g. accelerometer brands and models, number of axis, *epoch* length, non-wear period definition, minimum wear time per day or cut-points for MVPA) (Migueles et al., 2017). For instance, Adams et al. (2009; 2013) found up to 2,000 steps per day of variance in the total step-based cut-points when they were translated on the same sample and with the same methodology procedure, but with different MVPA cut-points. Additionally, it should be highlighted that the *epoch* set can also affect drastically the MVPA and, thus, the step-based cut-points. For example, adolescents' daily MVPA levels based on one-min *epochs* have been shown to be statistically significantly lower than those with three-second *epochs* (Aibar et al., 2014). Since adolescents' PA patterns are characterized by short bursts of quickly changing activity, 1-to-15-second *epochs* have been recommended

(Migueles et al., 2017). In this context, for instance, studies based on one-min *epochs* reported higher total step-based cut-points (i.e. 11,111−13,000 steps/day) (Adams et al., 2009; 2013; Mayorga-Vega et al., 2019) than those with the one-second *epochs* (i.e. 8,521 steps in the present study, and 9,701 steps/day in Benítez-Porres et al. (2016)) (as an example, data are based on the uncensored total steps translation of the MVPA calculated by the Evenson or 4-MET Freedson cut-points).

Similarly, with regard to the index test, since there are many different instruments (e.g. accelerometers, pedometers, mobile apps, or wristbands) and procedures (e.g. uncensored steps or censored steps) that are not completely comparable (Evenson et al., 2015; Strath & Rowley, 2017), the steps measure could also affect the step-based cut-points. Although in all the previous topic-related studies the devices were placed on adolescents' waist as in the present study, they did not agree with many other key methodological decisions such as the monitor brand and model, minimum wear time per day or non-wear period definition. Moreover, Adams et al. (2013) and Mayorga-Vega et al. 2019) examined the MVPA recommendation translation with both uncensored and censored daily total steps (i.e. with the same sample and methodological procedure within each study). For instance, for the Evenson MVPA cut-point these two previous studies found that censored total steps cut-points have about 2,500 steps fewer (Adams et al., 2013; Mayorga-Vega et al., 2019), being similar in males and females (Adams et al., 2013). Finally, statistical procedures could also affect the step-based cut-points. For instance, while Colley et al. (2012) carried out regression analyses, the rest of the previous studies performed ROC analyses. Additionally, among those studies that carried out ROC analyses, while most of the authors used the Youden index optimal cut-point (Benítez-Porres et al., 2016; Fontana et al., 2015; Mayorga-Vega et al., 2019), others used the balance method (Adams et al., 2009; Adams et al., 2013). Although no previous study has examined the differences between optimal cut-point methods, from the at least the 34 different optimal cut-point methods available today (Goksuluk et al., 2016), as an example, in the present study the optimal cut-points ranged from 5,680 to 12,308 steps/day (median = 9,167 steps/day).

Zhu et al. (2011) established that, after the development of criterion-referenced standards, the cross-validation of these thresholds using additional samples should be examined. Ideally, to examine the error only due to the fact of applying the cut-points in a different group of people, a similar sample from the same population should be assessed following exactly the same methodological procedures (Thomas et al., 2015). To our knowledge, the present study is the first to have extensively examined the accuracy of several daily total step-based cut-points with a subsample in adolescents using the same methodological procedures. As far as we know, Colley et al. (2012) is the only other study that cross-validated a step-based cut-point in a subsample using the same methodological procedures. Specifically, after establishing the 12,000-step cut-point with a subsample, when Colley et al. (2012) cross-validated it in another subsample they found that the 12,000-step cut-point had a good balance of sensitivity (0.83) and specificity (0.81), being better than when it was compared with the previously proposed 13,500-step cut-point (Sensitivity = 0.90, Specificity = 0.66). As in the present study, the above-mentioned authors measured steps by a waist-worn accelerometer. Afterwards, some authors cross-validated the accuracy of the daily total step-based cut-points proposed by previous studies. For instance, Adams et al. (2013) also found that the accuracy of the 12,000-step cut-point measured by a waist-worn accelerometer was adequate for the uncensored total steps (e.g. with Evenson MVPA cut-point: males, Sensitivity = 0.87, Specificity = 0.71, P = 0.75; females, Sensitivity = 0.76, Specificity = 0.81, P = 0.81). Recently, after examining the accuracy of all previously proposed daily total step-based cut-points in adolescents (Parra Saldías et al., 2018), found that for the uncensored total steps measured by a waist-worn accelerometer the 11,000/10,500 step-per-day cut-point (males/females) showed the highest accuracy (e.g. Sensitivity = 0.85, Specificity = 0.94, P = 0.93). Additionally, similar to the present study, when the most widely proposed daily step-based recommendations among adolescents were compared (i.e. 10,000 and 12,000 steps), although the 12,000-step cut-point had a better overall accuracy than the 10,000 steps/day (e.g. P = 0.92 vs. 0.83 and k = 0.57 vs. 0.45), the 10,000-step cut-point showed a better balance of sensitivity and specificity (Sensitivity/Specificity = 0.92/0.82 vs. 0.62/0.96). Finally, it must be noted that unlike in all the previous studies where the MVPA is based on one-minute *epochs*, due to the fact that adolescents' PA patterns are characterized by short bursts of quickly changing activity (Migueles et al., 2017), in the present study the one-second *epoch* was used instead. Among many other methodological reasons, differences in *epoch* lengths could also explain the above-mentioned outcomes inconsistency. For instance, using longer *epochs* artificially produces lower MVPA time, which in turn produces higher step-based cut-points, and vice versa. Regarding the steps/min- and peak 1-min cadence-based recommendations, however, to our knowledge, there are no previous cross-validity studies to compare with.

Strengths and limitations

To the best of our knowledge, the main strengths of the present study were that, taking account the best current evidence-based methodological decisions, it is the first one carried out with adolescents that: (a) statistically compares the accuracy of different daily steps index-based cut-points related to the daily 60 minutes of MVPA recommendation measured by a waist-worn accelerometer, as well as it examines this separately in males and females; (b) examines the steps cadence-based cut-points with true cadence; (c) examines the cross-validity of daily step-based cut-points with a similar subsample following the same methodological procedures, and (d) examines the cross-validity of daily steps/min- and peak 1-min cadence-based cut-points related to the MVPA recommendation. Therefore, since the steps per day have the advantage of being very simple to understand (Tudor-Locke et al., 2011), which is the main PA output measured by the popular consumer-wearable activity trackers (Althof et al., 2017), the present study represents an considerable advance in the area of objectively assessing and promoting adolescents' daily PA levels.

Regarding the limitations of the present study, on the one hand, due to human and material resource restrictions, a probability sample could not be examined and, thus, this limits the generalizability of the obtained outcomes to the particular studied setting. On the other hand, although only participants' data with at least one day with 600 minutes or more of valid wear time were analysed, the information about how much of the data is composed of participants who had low use (i.e. 1 day) of the accelerometer compared with those with high use (i.e. all 7 days) could affect the outcomes. Finally, another limitation lies in the fact that several methodological issues, such as the reference standard measurement, the index tests measurement and the statistical analyses procedures, may affect the step-based cut-points (Bossuy et al., 2015). For instance, it is worth mentioning that laboratory-based studies have observed that, as most activity monitors, the waist-worn accelerometer GT3X underestimates steps at low walking pace (Feito et al., 2012; Hickey et al., 2016; O'Brien et al., 2018; Tudor-Locke et al., 2015). However, the above-mentioned studies found that this accelerometer adjusted on the waist had a high validity from self-paced walking pace (Oberg et al., 1993; Waters et al., 1988) to running (Feito et al., 2012; Hickey et al., 2016; O'Brien et al., 2018; Tudor-Locke et al., 2015). In line with this scenario, the waist-worn accelerometer GT3X had also shown an adequate validity for assessing steps in free-living conditions (Feito et al., 2012; Hickey et al., 2016). However, in the present study, the best current evidence-based decisions were adopted. For instance, since the waist (hip) is considered the reference placement for assessing PA through accelerometry (Migueles et al., 2017), in line with all the previous topic-related studies (Adams et al., 2009; Adams et al., 2013; Benítez-Porres et al., 2016; Colley et al., 2012; Fontana et al., 2015; Mayorga-Vega et al., 2019), in the present study the accelerometer was placed on adolescents' waist. However, among the different consumer-wearable accelerometers, which represent the most common instrument in public health (Tudor-Locke et al., 2011), the use of wrist-worn monitors has become very popular in about the last 10 years (Strath & Rowley, 2017). Unfortunately, previous empirical studies have found that wrist- and waist-worn accelerometer steps outputs are not always comparable (Evenson et al., 2015; Tudor-Locke et al., 2015). Therefore, this issue limits the generalizability of the obtained outcomes to the particular studied methodological conditions (e.g. waist-worn accelerometers). When there is stronger evidence on the different methodological issues, future research studies translating the recommended 60 minutes of MVPA to the daily total steps in adolescents should be carried out with a probability sample. Moreover, future research studies should establish daily total steps cut-points measured by wrist-worn monitors in adolescents.

Conclusions

Total step- and step/min-based cut-points have high accuracy for translating the daily 60 minutes of MVPA recommendation measured by a waist-worn accelerometer in adolescents. Daily total step-based recommendations are preferable to those with steps/min and peak 1-min cadence because they are not only simpler but also more accurate for classifying adolescents as being or not being physically active. There was no difference between males and females. Considering both present and previous evidence, 10,000 steps/day measured by a waist-worn accelerometer seems to be a simple and accurate cut-point with which to classify both male and female adolescents. The findings of the present study significantly contribute to the scientific knowledge area, as well as they provide useful data for policy-makers regarding adolescents daily PA targets.

Disclosure statement

The authors report no conflict of interest. The funder had no role in the study design, data collection and analysis, decision to publish, or preparation of the manuscript.

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Geolocation information

Sample A: 37°10′31.9″N, 3°36′53.6″W, 37.175531, −3.614880; Sample B: 37° 08′37.6″N, 3°38′22.7″W, 37.143788, −3.639645

Key learning points

Daily total step-based recommendations are more accurate than those with steps/min and peak 1-min cadence for classifying adolescents as being physically active or inactive.

A 10,000 steps/day target measured by a waist-worn accelerometer is simple and accurate for both male and female adolescents.

There was no difference between males and females.

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