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How many daily steps are really enough for adolescents? A cross-validation study

¿Cuántos pasos diarios son realmente suficientes para los adolescentes? Un estudio de validación cruzada

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Abstract. The main purpose of the present study was to compare the accuracy of total daily steps thresholds associated to the recommended 60 min per day moderate-to-vigorous physical activity in adolescents. A total of 156 adolescents, 87 males and 69 females, participated in the present study. Objectively-measured moderate-to-vigorous physical activity and steps were assessed by GT3X accelerometers for eight consecutive days. The accuracy of the following total daily steps thresholds was calculated (males/females): 9,930, 11,714, 12,000, 11,000/10,500, 14,000/11,500, 13,000/12,000, 8,500/7,500, 11,500/9,000, 10,500/9,500, 12,118, 12,118/12,605, and 10,000. The results of accuracy both uncensored and censored total daily steps cut-off points ranged from low to high. For the uncensored total daily steps, the cut-off 11,000 for males and 10,500 for females showed the best results: Sensitivity = .85; Specificity = .94; Youden's index = .78; Proportion of agreement = .93, and Kappa coefficient = .67, $p < .001$. For the censored total daily steps, the 10,000 cut-off score showed the best results: Sensitivity = .77; Specificity = .95; Youden's index = .72; Proportion of agreement = .93, and Kappa coefficient = .65, $p < .001$. Among adolescents for accelerometry-measured total daily steps the 11,000 for males and 10,500 for females cut-off points should be used. For population guidelines regarding health-enhancing steps in adolescents, the cut-off point of 10,000 daily steps seems to be the most appropriate.
Keywords: Steps/day, steps per day, moderate-to-vigorous physical activity, physical activity recommendations, accuracy, cut-off points, youth, young people.

Resumen. El propósito principal del presente estudio fue comparar la precisión de los umbrales de pasos diarios totales asociados a la recomendación de 60 minutos por día de actividad física moderada-vigorosa en adolescentes. Un total de 156 adolescentes, 87 varones y 69 mujeres, participaron en el presente estudio. La actividad física moderada-vigorosa y pasos se evaluaron objetivamente con acelerómetros GT3X durante ocho días consecutivos. Se calculó la precisión de los siguientes umbrales de pasos diarios totales (varones/mujeres): 9.930, 11.714, 12.000, 11.000/10.500, 14.000/11.500, 13.000/12.000, 8.500/7.500, 11.500/9.000, 10.500/9.500, 12.118, 12.118/12.605 y 10.000. Los resultados de precisión para los puntos de corte de los pasos diarios ajustados y no ajustados variaron de bajo a alto. Para los pasos diarios no ajustados, los puntos de corte 11.000 para los varones y 10.500 para las mujeres mostraron los mejores resultados: Sensibilidad= 0,85; Especificidad= 0,94; Índice de Youden= 0,78; Proporción de acuerdo= 0,93, y coeficiente de Kappa= 0,67, $p < 0,001$. Para los pasos diarios ajustados, el puntaje de corte de 10.000 mostró los mejores resultados: Sensibilidad= 0,77; Especificidad= 0,95; Índice de Youden= 0,72; Proporción de acuerdo= 0,93, y coeficiente de Kappa= 0,65, $p < 0,001$. Entre los adolescentes para los pasos diarios totales medidos con acelerometría se deberían utilizar los puntos de corte 11.000 para los varones y 10.500 para las mujeres. Para las recomendaciones a nivel poblacional sobre los pasos relacionados con la salud en los adolescentes, el punto de corte de 10.000 pasos diarios parece ser el más apropiado.
Palabras clave: Pasos/día, pasos por día, actividad física moderada-vigorosa, recomendaciones de actividad física, precisión, puntos de corte, juventud, jóvenes.

Introduction

Engaging in regular physical activity (PA) is widely acknowledged as a key issue of health and quality of life in youth (Janssen & Leblanc, 2010; Poitras et al., 2016). Unfortunately, young people are insufficiently physically active (World Health Organization, 2014), especially during adolescence when their PA levels drop drastically (Silva, et al., 2011). Worldwide about 81% of adolescents, 78% males and 84% females, do not achieve the daily recommendation of PA (World Health Organization, 2014). Therefore, encouraging adolescents to meet the PA guidelines is considered a public health priority (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). However, PA guidelines expressed in terms of frequency, duration, and intensity may not be easily understood for both adolescents and their parents (Tudor-Locke et al., 2011). Despite the fact that consumer-wearable step-based monitors such as waist pedometers, activity bands or Smartphone-based pedometer applications only provide a measure of total PA, they are inexpensive, easy to use and its output is reliable and simple to understand (Baumgartner, Jackson, Mahar, & Rowe, 2015). Additionally, the simple step output is lastly gaining increased credibility as a reasonable approximation of daily PA (Craig, Cameron, Griffiths, & Tudor-Locke, 2010). These consumer-wearable activity monitors may represent, therefore, a feasible instrument to objectively assess and promote adolescents' daily PA (Da Silva, Fontana, Callahan, Mazzardo, & De Campos, 2015; Pulido González, Sánchez-Oliva, Sánchez-Miguel, González-Ponce, & García-Calvo, 2016; Tudor-Locke et al., 2011).

Nowadays providing daily PA recommendations for young people through steps is required. Currently, there are not strong evidence-based recommendations about how many daily steps are enough in adolescents. Up to date, the empirical studies examining the steps/day translation of the daily recommendation of 60 min MVPA in adolescents are scarce and changeable, ranging from 7,500 to 14,000 steps/day (Adams, Caparosa, Thompson, & Norman, 2009; Adams, Johnson, & Tudor-Locke, 2013; Colley, Janssen, & Tremblay, 2012; Fontana, da Silva, Marston, Finn, & Gallagher, 2015). Zhu, Mahar, Welk, Going, and Cureton (2011) establish that, after the development of criterion-referenced standards, the cross-validation of these cut-off scores using additional samples must be examined. To our knowledge, however, no study to date has extensively examined the accuracy of all previous daily steps cut-off scores in adolescents. Consequently, the main purpose of the present study was to compare the accuracy of free-living total daily steps thresholds associated to the recommended 60 min per day MVPA in adolescents. A secondary purpose of this study was to compare the cardiorespiratory fitness levels between adolescents who met and did not meet the daily steps recommendations.

Method

Participants

The protocol of the present study was first approved by the Ethical Committee of the University of [omitted for blind review]. Then, all the 10 municipalized schools of basic education level belonging to the district called Nuñoa were contacted; 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

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were informed about the project and the permission to conduct the study was requested. After approvals of four schools were obtained, eighth-grade students and their legal guardians were fully informed about all the features of the present study. Adolescents' written informed assent and their parents/legal guardians' written informed consent were obtained to take part in the study.

A total of 156 adolescents, 87 males and 69 females, agreed to participate in the present study and met the inclusion criteria. The inclusion criteria were: (a) being enrolled in the eighth grade of any selected school; (b) being free of any health disorder which would make them unable to undergo PA; (c) presenting the corresponding signed written informed assent by the own adolescents, and (d) presenting the corresponding signed written informed consent by their parents or legal guardians. The exclusion criteria were: (a) not having at least two weekdays with the valid wear time, and (c) not having at least one weekend day with the valid wear time.

Table 1
Steps/day translation of the recommendation of 60 min moderate-to-vigorous physical activity for adolescents

Reference	Gender	Age (years)	Instruments	Steps	MVPA	Optimal cut-off point (steps/day)	Outcomes
Adams et al. (2009)	12 males and 28 females	11-16	Actigraph 7164	Uncensored	Freedson 3 METs	9,930	AUC=.89, TPF=.84, TNF=.81
					Freedson 4 METs	11,714	AUC=.94, TPF=.75, TNF=.81
Coley et al. (2012)	837 males and females	6-19	Actical	Uncensored	Actical	12,000	R^2=.68
Adams et al. (2013)	646 males/ 656 females	12-17	Actigraph 7164	Uncensored	Freedson 3 METs	11,000/10,500	AUC=.84/.85, *P*=.74/.76
					Freedson 4 METs	14,000/11,500	AUC=.91/.84, *P*=.84/.77
					Evenson	13,000/12,000	AUC=.89/.90, *P*=.80/.83
				Censored	Freedson 3 METs	8,500/7,500	AUC=.99/.88, *P*=.79/.79
					Freedson 4 METs	11,500/9,000	AUC=.93/.87, *P*=.88/.82
					Evenson	10,500/9,500	AUC=.93/.93, *P*=.83/.88
Fontana et al. (2015)	93 males and 108 females	11-12	YAMAX SW-200 (steps),	Pedometer	Freedson 4 METs	12,118	AUC=.85, TPF=.78, TNF=.85
	93 males		Actigraph GT3X			12,118	AUC=.88
	108 females		(MVPA)			12,605	AUC=.80

Note. MVPA = Moderate-to-vigorous physical activity; AUC = Area under the curve; TPF = True Positive Fraction (sensitivity); TNF = True Negative Fraction (specificity); R^2 = Regression coefficient; *P* = Proportion of agreement.

Measures

Physical activity. Objectively-measured MVPA and steps were assessed by GT3X accelerometers (ActiGraph, LLC, Pensacola, FL, USA). The GT3X accelerometer is a compact (3.8 x 3.7 x 1.8 cm), lightweight (27 g), and triaxial monitor designed to record time varying accelerations ranging in magnitude from approximately .05 to 2.50 Gs. The accelerometer output is digitized by a 12-bit analog-to-digital converter at rates of 30-100 Hz. Then, the signal passes through a digital filter that band limits the accelerometer to the frequency range of .25-2.5 Hz. The filtered signal is then rectified and integrated over a user-specified interval time known as *epoch*. At the end of each *epoch*, the summed value known as *activity count* or simply *counts* is stored in memory and the integrator is reset. The *counts* obtained in a particular *epoch* are proportional to the intensity of the PA during the measured period (Trost, Loprinzi, Moore, & Pfeiffer, 2011).

Adolescents were instructed to wear the accelerometer for eight consecutive days and then data were downloaded and analyzed using the *ActiLife Lifestyle Monitoring System Software* version 6.11.3. To avoid biases because of participants' reactivity, the first day with the data obtained was considered as a familiarization day and it was not used for statistical analyses. A minimum of two weekdays and one weekend day with at least 600 min of valid wear time per day was set (Mattocks et al., 2008). Non-wear periods were set with a minimum length of 60 min of consecutive zero-count *epochs* with up to two minutes spike tolerance (Oliver, Badland, Schofield, & Shepherd, 2011). To determine the time engaged in MVPA, Evenson's cut-off points (i.e., e» 2,296 counts/min) were used (Evenson, Catellier, Gill, Ondrak, & McMurray, 2008; Trost et al., 2011). Steps were assessed by within-instrument processing of the number of cycles in the accelerometer signal or *cycle counts* (Tudor-Locke, Ainsworth, Thompson, & Matthews, 2002).

Since the main purpose of the present study was to provide a readily translatable daily steps conversion of the recommended 60 min daily MVPA, and consumer-wearable activity monitors are the most commonly used instruments in public health and clinical applications (Adams et al., 2013), accelerometer-measured steps (i.e., uncensored steps) were adjusted to make it more comparable to consumer-wearable activity monitors output. According to previous studies conducted with adolescents (Adams et al., 2013; Tudor-Locke, Johnson, & Katzmarzyk, 2010), uncensored steps were adjusted by censoring those steps which were taken below 500 *counts*/min (i.e., censored steps). Finally, habitual MVPA and uncensored/censored steps were calculated as: ((5 × average outcomes of valid weekdays) + (2 × average outcomes of valid weekend days))/7. Adolescents' habitual MVPA was categorized as achieving or not the recommendation of 60 min daily MVPA (World Health Organization, 2010) and habitual uncensored/censored steps were categorized as achieving or not the daily steps thresholds established in previous empirical studies (Table 1) and two reviews (Da Silva et al., 2015; Tudor-Locke et al., 2011) conducted with adolescents. ActiGraph accelerometer-measured MVPA and steps has shown high validity among adolescents (Arvidsson, Fitch, Hudes, Tudor-Locke, & Fleming, 2011; Santos-Lozano et al., 2013; Trost et al., 2011).

Body composition. Body composition was assessed using the tests proposed in the High Priority ALPHA Health-Related Fitness Test Battery (Ruiz et al., 2011): Body mass and height (body mass index), and waist circumference. Body composition measures were performed with the participants in shorts and T-shirts and barefoot. Two measures of each test were performed and then the mean of each one was retained. For the body mass measure, the participants stood in the centre of the scale (Tanita HD 313, Arlington, USA; accuracy = .1 kg) without support and with their weight distributed evenly on both feet. For the body height assessment, the students stood with the feet together, their heels, buttocks and upper part of the back touching the scale (SECA 206®, Hamburg, Germany; accuracy = .1 cm), and their head placed in the Frankfort plane. Body mass index was calculated later as body mass in kilograms divided by the square of body height in meters (kg/m^2). Then, participants' body weight status was categorized as non-overweight and overweight/obesity according to the body mass index international cut-off scores (Cole, Bellizzi, Flegal, & Dietz, 2000).

For the waist circumference measure, the participants stood erect with the abdomen relaxed, the arms at the sides and the feet together. Participants' waist was around with a non-elastic tape (Lufkin W606PM, Texas, USA; accuracy = .1 cm), in a horizontal plane, at the level of the narrowest part of the torso, between the spine iliaca superior and the costal edge in the midaxillary line. Measurements were taken at the end of a normal expiration without the tape compressing the skin. Then, participants were categorized as having or not excess central body fat according to the waist circumference cut-off values (Gómez-Campos et al., 2015). Body mass index and waist circumference have demonstrated high validity among adolescents (Castro-Piñero et al., 2010).

Cardiorespiratory fitness. Cardiorespiratory fitness was assessed using the 20-meter shuttle run test (Léger, Mercier, Gadoury, & Lambert, 1988), which is the cardiorespiratory fitness test proposed in the High Priority ALPHA Health-Related Fitness Test Battery (Ruiz et al., 2011). The participants ran between two parallel lines placed 20 meters apart (laps), in the rhythm marked by a recorded beep. The starting speed was 8.5 km/h and it increased .5 km/h approximately every minute (stage). The test ended when the participants stopped running because of fatigue or failed to reach the line before the next signal for two consecutive times. Participants were allowed to perform the test once and the total number of completed stages was retained. The maximum oxygen uptake (ml/kg/min) was later estimated using the Leger's equation (Léger et al., 1988). Then, participants were categorized as having a healthy or unhealthy cardiorespiratory fitness profile according to the maximum oxygen uptake cut-off points (Welk, Laurson, Eisenmann, &

Cureton, 2011). The 20-meter shuttle run test has demonstrated adequate validity among adolescents (Mayorga-Vega, Aguilar-Soto, & Viciana, 2015; Mayorga-Vega, Bocanegra-Parrilla, Ornelas, & Viciana, 2016).

Procedures

Data collection was carried out during physical education classes during the months of July to October of 2015. All measurements were performed by the same evaluator, using the same instruments and under the same conditions. During an evaluation session, accelerometers were fitted on the participants' right hip by using an elastic waistband. Participants were instructed to wear the accelerometer for eight consecutive days, from waking to bedtime and to take the accelerometer off only when engaged in aquatic activities or taking a shower. Adolescents were urged to maintain their normal PA habits during the monitoring period.

During another evaluation session, anthropometric measurements (i.e., body mass, body height and waist circumference) were collected without any previous warm-up. Afterwards, in another evaluation session, participants' cardiorespiratory fitness was assessed by the 20-meter shuttle run test. Prior to the cardiorespiratory fitness test, the participants completed a standardized warm-up consisting of five minutes of running from low to moderate intensity. The 20-meter shuttle run test was performed in an indoor sports facility with a non-slippery floor.

Statistical analysis

Descriptive statistics (median –interquartile range- or percentage) for all the variables of the included participants were calculated. Since some continuous variables did not follow a normal distribution, a non-parametric approach was used. The Mann-Whitney U test (continuous data) and chi-squared test (categorical data) were first conducted to compare the general characteristics between male and female participants. Afterward, the accuracy of the total daily steps thresholds were calculated as follow: a) True Positive Fraction (Sensitivity); b) True Negative Fraction (Specificity); c) Youden's index; d) Proportion of agreement, and e) Kappa coefficient. Then, the Mann-Whitney U test was used to compare the maximum oxygen uptake levels between adolescents who did and did not meet the total daily steps recommendations. The *r* effect sizes were calculated to examine the magnitude of these comparisons (Field, 2013). Finally, the relative risk or risk ratio (RR), with the 95% confident interval (95% CI), was used to examine the probability of having a healthy cardiorespiratory fitness profile between adolescents who did and did not achieve the total daily steps recommendations. Due to the limited number of participants, all statistical analyzes were performed with males and females together. In this line, four comparisons could not be performed because of the low number of some subcategories ($n < 8$). All statistical analyses were performed using the SPSS version 21.0 for Windows (IBM® SPSS® Statistics). The statistical significance level was set at p d» .05.

Table 2

General characteristics (median –interquartile range- or percentage) of the included participants and differences between males and females

	Total	Males	Females
	(*n* = 126)	(*n* = 70)	(*n* = 56)
Age (years)	13.0 (1.0)	13.0 (1.0)	13.0 (1.0)
Body mass (kg)	56.8 (14.9)	56.8 (16.1)	56.7 (13.3)
Body height (cm)	163.0 (10.0)	165.5 (11.3)	159.0 (6.8)**
Body mass index (kg/m²)	21.36 (5.1)	20.7 (4.1)	22.0 (5.0)
Overweight/obesity (no/yes)	66.7/33.3	70.0/30.0	62.5/37.5
Waist circumference (cm)	74.0 (12.5)	74.3 (13.3)	73.5 (12.8)
Excess central body fat (no/yes)	82.5/17.5	78.6/21.4	87.5/12.5
Habitual daily MVPA (min)	29.9 (26.9)	33.1 (31.1)	20.7 (22.8)**
60 min daily MVPA (yes/no)	10.3/89.7	15.7/84.3	3.6/96.4*
Habitual daily uncensored steps	8122.0 (3773.8)	9183.7 (3933.6)	7805.4 (3039.1)*
Habitual daily censored steps	6609.3 (3442.6)	7397.5 (3580.1)	6260.9 (3243.3)*
Maximum oxygen uptake (ml/kg/min)	41.1 (7.9)	42.1 (7.9)	36.7 (5.2)**
Healthy cardiorespiratory fitness (yes/no)	43.7/56.3	48.6/51.4	37.5/62.5

Note. MVPA = Moderate-to-vigorous physical activity.
* $p < .05$ and ** $p = .001$ for the Mann-Whitney U test (continuous data)/chi-squared test (categorical data).

Results

From the initial sample of 156 adolescents (87 males and 69 females) who agreed to participate and met the inclusion criteria, 126 adolescents (70 males and 56 females) passed the exclusion criteria (i.e., an attrition rate of 19.2%). Table 2 shows the general characteristics of the included participants. The results of the Mann-Whitney U test showed that male adolescents had statistically significant higher values of body height, habitual daily MVPA, habitual daily uncensored/censored steps and maximum oxygen uptake than female adolescents ($p < .05$). Additionally, the chi-square analysis showed that there was a statistically significant greater proportion of male adolescents meeting the recommendation of 60 min daily MVPA than female adolescents ($p < .05$). However, statistically significant differences in terms of body mass, body mass index, overweight/obesity, waist circumference, excess central body fat, and healthy cardiorespiratory fitness between males and females were not found ($p > .05$).

Table 3 shows the comparison of the accuracy of the total daily steps recommendations associated to 60 min of MVPA in adolescents. The 10.3% of the adolescents met the recommendation of 60 min daily MVPA, while between 7.1-54.0% (median = 11.1%) and 1.6-29.4% (median = 7.9%) achieved the cut-off scores of the uncensored and censored daily total steps, respectively. The results of the accuracy of the total daily steps cut-off points with the uncensored total steps ranged from low to high [median (minimum-maximum)]: Sensitivity = .62 (.38-1.00); Specificity = .95 (.51-.96); Youden's index = .57 (.35-.78); Proportion of agreement = .91 (.56-.93), and Kappa coefficient = .54 (.18-.67), all $p < .001$. Regarding the results with the censored total steps, the accuracy of the cut-off points of total daily steps also ranged from low to high [median (minimum-maximum)]: Sensitivity = .54 (.15-.92); Specificity = .97 (.78-1.00); Youden's index = .51 (.15-.72); Proportion of agreement = .92 (.79-.93), and Kappa coefficient = .54 (.25-.65), all $p < .001$. According to the results of the present cross-validation study, among adolescents for accelerometry-measured total daily steps the 11,000 for males and 10,500 for females cut-off points should be used. For population guidelines regarding health-enhancing steps among adolescents (i.e., where consumer-wearable activity monitors are more widely used), the cut-off point of 10,000 daily steps seems to be the most appropriate.

Table 3

Accuracy of the total daily steps recommendations associated to 60 min of moderate-to-vigorous physical activity

	Cut-off points	Uncensored daily steps						Censored daily steps					
References	(Males/females)	%TP	TPF	TNF	*J* max	*P*	*k*	%TP	TPF	TNF	*J* max	*P*	*k*
Adams et al. (2009)	9,930	25.40	.92	.82	.75	.83	.45*	13.49	.77	.94	.71	.92	.62*
Adams et al. (2009)	11,714	11.11	.62	.95	.56	.91	.54*	7.94	.54	.97	.51	.93	.57*
Coley et al. (2012)	12,000	10.32	.62	.96	.57	.92	.57*	6.35	.46	.98	.44	.93	.54*
Adams et al. (2013)	11,000/10,500	14.29	.85	.94	.78	.93	.67*	9.52	.62	.96	.58	.93	.60*
Adams et al. (2013)	14,000/11,500	7.14	.38	.96	.35	.90	.40*	1.59	.15	1.00	.15	.91	.25*
Adams et al. (2013)	13,000/12,000	9.52	.62	.96	.58	.93	.60*	3.97	.23	.98	.21	.90	.29*
Adams et al. (2013)	8,500/7,500	53.97	1.00	.51	.51	.56	.18*	29.37	.92	.78	.70	.79	.39*
Adams et al. (2013)	11,500/9,000	21.43	.69	.84	.53	.83	.36*	11.11	.62	.95	.56	.91	.54*
Adams et al. (2013)	10,500/9,500	19.84	.85	.88	.72	.87	.51*	11.11	.62	.95	.56	.91	.54*
Fontana et al. (2015)	12,118	10.32	.62	.96	.57	.92	.57*	5.56	.38	.98	.37	.92	.46*
Fontana et al. (2015)	12,118/12,605	10.32	.62	.96	.57	.92	.57*	5.56	.38	.98	.37	.92	.46*
Tudor-Locke et al. (2011)	10,000	25.40	.92	.82	.75	.83	.45*	12.70	.77	.95	.72	.93	.65*
Da Silva et al. (2015)	12,000	10.32	.62	.96	.57	.92	.57*	6.35	.46	.98	.44	.93	.54*

Note. %TP= Percentage of total positive cases according to the specific step cut point; TPF = True Positive Fraction (sensitivity); TNF = True Negative Fraction (specificity); *J* max = Youden's index; *P* = Proportion of agreement; *k* = Kappa coefficient.
* $p < .001$

Table 4 shows the comparison of cardiorespiratory fitness levels between adolescents who did and did not meet the total daily steps recommendations. The results of the Mann-Whitney U test showed that adolescents who achieved the daily steps recommendations had statistically significantly higher maximum oxygen uptake levels than those that did not achieve the recommendations (p d» .05, $r = .17$-.26), except for the cut-off points 14,000/11,500 for uncensored steps, 8,500/7,500 for both uncensored and censored steps, and 11,500/9,000 for uncensored steps. Additionally, the relative risk results showed that adolescents who met the following daily steps recommendations had a

statistically significant higher probability of having a healthy cardiorespiratory fitness profile than those who did not meet them [RR (95% CI)]: 3.02 (1.06-8.67) times for the 11,000/10,500 uncensored steps, 3.35 (1.37-8.23) and 3.72 (1.10-12.60) for the 11,500/9,000 uncensored and censored steps, respectively, and 2.83 (1.14-7.02) for the 10,500/9,500 uncensored steps. However, for the other comparisons statistically significant differences were not found ($p > .05$). Finally, it is worth noting that due to the low number of four categories ($n < 8$) the corresponding comparisons were not calculated.

Table 4
Comparison of cardiorespiratory fitness levels (median -interquartile range-) between adolescents who met (above column) and did not meet (below column) the total daily steps recommendations[a]

	Cut-off points	Uncensored daily steps				Censored daily steps			
References	(Males/females)	Below	Above	*r*	RR (95% CI)	Below	Above	*r*	RR (95% CI)
Adams et al. (2009)	9,930	39.4 (7.9)	41.6 (7.5)*	.22	1.67 (.75-3.74)	4.3 (7.9)	43.8 (7.3)*	.19	2.71 (.93-7.86)
Adams et al. (2009)	11,714	40.7 (7.9)	42.5 (6.5)*	.17	2.58 (.81-8.21)	41.1 (7.9)	44.3 (9.0)*	.22	3.31 (.81-13.43)
Coley et al. (2012)	12,000	41.1 (7.9)	43.8 (8.1)*	.18	2.25 (.69-7.30)	41.1 (7.9)	44.3 (7.4)*	.21	4.22 (.82-21.82)
Adams et al. (2013)	11,000/10,500	39.9 (7.9)	43.8 (7.2)*	.21	3.02 (1.06-8.67)	41.1 (7.9)	43.8 (9.6)*	.18	2.85 (.81-10.02)
Adams et al. (2013)	14,000/11,500	41.1 (7.9)	41.1 (6.5)	.10	2.78 (.66-11.64)	-	-	-	-
Adams et al. (2013)	13,000/12,000	41.1 (7.9)	43.8 (9.6)*	.18	2.85 (.81-10.02)	-	-	-	-
Adams et al. (2013)	8,500/7,500	40.7 (7.9)	41.1 (7.6)	.03	1.54 (.76-3.15)	39.4 (7.9)	41.1 (8.9)	.14	1.82 (.84-3.94)
Adams et al. (2013)	11,500/9,000	39.4 (7.9)	41.1 (6.3)	.15	3.35 (1.37-8.23)	40.7 (7.9)	43.8 (6.5)*	.19	3.72 (1.10-12.60)
Adams et al. (2013)	10,500/9,500	39.4 (7.9)	43.8 (5.8)*	.26	2.83 (1.14-7.02)	40.7 (7.9)	42.5 (6.5)*	.17	2.58 (.81-8.21)
Fontana et al. (2015)	12,118	41.1 (7.9)	43.8 (8.1)*	.18	2.25 (.69-7.30)	-	-	-	-
Fontana et al. (2015)	12,118/12,605	41.1 (7.9)	43.8 (8.1)*	.18	2.25 (.69-7.30)	-	-	-	-
Tudor-Locke et al. (2011)	10,000	39.4 (7.9)	41.6 (7.5)*	.22	1.67 (.75-3.74)	40.7 (7.9)	43.8 (8.5)*	.19	2.41 (.82-7.10)
Da Silva et al. (2015)	12,000	41.1 (7.9)	43.8 (8.1)*	.18	2.25 (.69-7.30)	41.1 (7.9)	44.3 (7.4)*	.21	4.22 (.82-21.82)

Note. $r = r$ effect sizes; RR (95% CI) = Relative risk (95% confident interval); [a] Comparisons with one group with less than eight cases were not calculated. * $p = .05$ for the Mann-Whitney U test.

Discussion

The main purpose of the present study was to compare the accuracy of free-living total daily steps thresholds associated to the recommended 60 min per day MVPA in adolescents. The results of the accuracy of the total daily steps standards with both uncensored and censored total steps ranged from low to high. According to the results of the present cross-validation study, among adolescents for accelerometry-measured total daily steps cut-off points of 11,000 for males and 10,500 for females should be used. For population guidelines regarding health-enhancing steps among adolescents (i.e., where consumer-wearable step-based monitors are more widely used), the recommendation of 10,000 daily steps seems to be the most appropriate. Similarly to the present study, Tudor-Locke et al. (2011) in their topic-related literature review suggested that adolescents should achieve at least 10,000 steps/day. Logically, additional health benefits can come from accumulating more steps per day.

Zhu et al. (2011) establish that, after the development of criterion-referenced standards, the cross-validation of these cut-off scores using additional samples must be examined. To our knowledge the present study is the first one that has extensively examined the accuracy of several daily steps cut-off scores in adolescents. Similar to the present study, to date the cross-validation of the accuracy of only the 12,000 and 13,500 steps standards for adolescents were examined. First, Colley et al. (2012) cross-validated the 13,500 steps threshold recommended by the Active Healthy Kids Canada (2010). The 13,500 steps per day recommendation showed a bad balance of sensitivity (.90) and specificity (.66), leading to an underestimation in proportion meeting the target of up to 8.4%. Later, Adams et al. (2013) examined the cross-validity of the 12,000 steps threshold established by Colley et al. (2012), which was then taken for the next following recommendations of the Active Healthy Kids Canada (2015, 2016). Adams et al. (2013) also found that in most of the cases the standard of 12,000 steps per day was too high, reaching a percentage of false negative (i.e., 1 - specificity) up to 52 and 82 for uncensored and censored daily steps, respectively. For instance, Adams et al. (2013) found that meanwhile the 11,000/10,500 standards showed a good balance of sensitivity/specificity, for the 12,000 steps it was poor, reaching a false negative rate of 38% and 52% for male and female adolescents. Therefore, in line with the present study, the Active Healthy Kids Canada should still suggest a lower daily steps recommendation for adolescents.

In the previous studies with adolescents examining the steps/day translation of the daily recommendation of 60 min of MVPA a wide range of different daily steps targets have been proposed, ranging from 7,500 to 14,000 steps/day (Adams et al., 2009, 2013; Colley et al., 2012; Fontana et al., 2015). Besides the differences in the PA patterns of the samples, variation between instruments and methodological issues of the studies could contribute to this variability in the daily steps standards. Accelerometer-measured PA has shown high validity among adolescents (Santos-Lozano et al., 2013; Trost et al., 2011), but the raw data are not interpretable. Multiples pre- and post-data collection decisions must be used to translate this information to produce data on time, duration and intensity of PA (Cain, Sallis, Conway, Van Dyck, & Calhoon, 2013; Calahorro et al., 2015). Any collection decision such as device placement, sample rate, number of axis, epoch length, days of wearing the device, definition of non-wear periods, minimum wear time per day, minimum number of valid days, or cut points for MVPA may influence drastically the PA outcomes (e.g., Banda et al., 2016; Ojiambo et al., 2011). Unfortunately, to date there is not a wide consensus regarding the ideal decision rules for scoring accelerometer data in adolescents (Cain et al., 2013; Calahorro et al., 2015).

It is worth noting that in the present study the MVPA was defined as e» 4 METs, instead of the 3 METs typically used for adults (Baumgartner et al., 2015). Although there is still a debate within the field regarding the selection of MET intensity thresholds for children and adolescents (Harrell et al., 2005; Ridley & Olds, 2008), the 4 METs thresholds have been suggested in order to account for their higher level of resting energy expenditure compared with adults (Harrell et al., 2005). Additionally, there is growing evidence that in children and adolescents brisk walking, a key behavioral indicator of moderate-intensity PA, is associated with an energy cost of approximately 4 METs (Ridley, Ainsworth, & Olds, 2008). In this line, although accelerometry-measured MVPA different cut points for adolescents are available, Evenson's cut-off point was used because it is based on 4 METs threshold and, also, it has shown to be the most valid among adolescents (Trost et al., 2011).

A secondary purpose of this study was to compare the cardiorespiratory fitness levels between adolescents who do and do not meet the daily steps recommendations. The results of the present study showed that adolescents who achieved the daily steps recommendations tend to have a higher mean maximum oxygen uptake level and a higher probability of having a healthy cardiorespiratory fitness profile than those that did not achieve the recommendations. However, not all the comparisons were statistically significant. It is worth noting that adolescents who met the 11,000/10,500 and 10,000 daily steps standards have a higher mean maximum oxygen uptake level, as well as a higher probability of having a healthy cardiorespiratory fitness profile for the 11,000/10,500 cut-off points, than those that did not meet them.

In the present study male and female adolescents on average obtained 42 and 37 ml/kg/min, respectively, being similar to the estimated median of cardiorespiratory fitness level among adolescents worldwide (e.g., for 13-year-old boys and girls it was estimated 45 and 40 ml/kg/min, respectively) (Tomkinson et al., 2016). As regards the percentage of participants that met a healthy cardiorespiratory fitness level, meanwhile the percentage of male adolescents was similar to the nationally representative sample in Chile (49% and 45%, respectively) (Cortinez-O´Ryan & Aguilar-Farias, 2017), in the present sample the percentage of females reaching the healthy zone was considerably higher (38% vs. 16%, respectively) (Cortinez-O´Ryan & Aguilar-Farias, 2017). In contrast, the worldwide estimate of adolescents having a healthy cardiorespiratory fitness level was significantly higher than in the sample of the present study (e.g., approximately 75% and 55% of 13-year-old

boys and girls, respectively) (Tomkinson et al., 2016).

Besides a translation of time in MVPA, steps/day recommendations could also be established by studies that relate the step-defined PA to desired health outcomes. Although total PA such as steps, and not only MVPA, has shown to be an important positive predictor of several health-related outcomes (Poitras et al., 2016), to our knowledge there is no study comparing the cardiorespiratory fitness levels between adolescents who do and do not meet the daily steps recommendations. However, a similar study was located that examined steps/day related to indicators of healthy vs. unhealthy body composition in adolescents (Dollman, Olds, Esterman, & Kupke, 2010). Dollman et al. (2010) using a ROC analysis found that for male adolescents the 11,000 steps/day cut-off points distinguished between adolescents with normal weight and overweigh/obese. However, the optimized cut point for female adolescents (i.e., 14,000 daily steps) did not significantly distinguish between those who were classified as normal weight versus overweight.

Strengths and limitations

Regarding the strengths of the present study, it should be highlighted that it is the first cross-validation study that extensively compare the accuracy of free-living total daily steps thresholds associated to the recommended 60 min per day of MVPA in adolescents. Cross-validation is a validation approach consisting in testing the accuracy of a cut-off point on an independent sample of individuals similar to the group in which the threshold was previously developed (Baumgartner et al., 2015). When the cross-validation results are satisfactory, cut-off points can be generalized to the same population with confidence. On the contrary, if the cut-off standard does not work well for the cross-validation sample, it has little value in generalizing to the studied population. Therefore, after the development of criterion-referenced standards, the cross-validation of these cut-off scores using additional samples has been considered a necessary step (Zhu et al., 2011). It should be also highlighted that in the present study the cross-validation of the censored steps that are more comparable with consumer-wearable step-based monitors was also examined.

Another strength was the fact of comparing the cardiorespiratory fitness levels between adolescents who do and do not meet the daily steps recommendations. Cardiorespiratory fitness has demonstrated to be a powerful marker of ideal cardiovascular health in adolescents (Ruiz et al., 2015; Welk et al., 2011), which can be influenced considerably by engaging in regular PA (Poitras et al., 2016). Although achieving the daily recommendation of at least 60 min of MVPA is widely supported (Poitras et al., 2016), up to date the validity of daily steps thresholds for discriminating adolescents with health-related cardiorespiratory fitness was lacking.

As regards the limitations of the present study, the main ones were related to the relatively small sample. Examining the cross-validation based on small samples is simply less generalizable than in large-sized studies. Due to the low number of participants, potentially different subcategories such as males and females had to be examined together. Additionally, because of the small number of participants in some subcategories, the comparison of maximum oxygen uptake levels between adolescents who did and did not meet the total daily steps recommendations with some cut-off scores could not be calculated. Therefore, further research studies should cross-validate the daily steps cut-off points with larger samples and separately by sex. Additionally future research studies with concurrently worn accelerometers and pedometers may produce a more accurate MVPA translation of pedometer-measured daily steps. Further intervention studies with adolescents are also needed to examine the dose-response of the recommended steps/day standards associated with various health parameters.

Conclusions

Although there is no simple answer to the question regarding the steps/day translation of the recommendation of 60 min MVPA for adolescents, based on the results of the present cross-validation study, accelerometry-measured total daily steps cut-off points of 11,000 for males and 10,500 for females seem to be the most appropriate. For population guidelines regarding health-enhancing steps, however, 10,000 daily steps seem to be the most practical and adequate pedometer-based cut-off point. It is also worth noting that adolescents who met the 11,000/10,500 and 10,000 daily steps standards have a higher mean maximum oxygen uptake levels, as well as a higher probability of having a healthy cardiorespiratory fitness profile for the 11,000/10,500 cut-off points, than those that did not meet them. Logically, additional health benefits could come from accumulating more steps per day. The present study significantly contributes to the evidence-based recommendations about how many daily steps are enough in adolescents. This knowledge may help policy-makers to provide accurate daily step-based guidelines that simplify PA recommendations for adolescents.

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