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

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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 = .77; Specificity = .95; Youden’s index = .72; 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 accelerometer-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.

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 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 largely 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 (Du Silva, Fontana, Callahan, Mazzardo, & De Campos, 2015; Pulido González, Sánchez-Obiva, 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
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.

Measures

Physical activity. Objective-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 0.5 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 0.25-2.5 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 of slight movement (Oliver, Badland, Schofield, & Shepherd, 2011). To determine the time engaged in MVP A, Evenson’s cut-off points (i.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: $(5 \times \text{average outcomes of valid weekdays}) + (2 \times \text{average outcomes of valid weekend days})$. 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 (Du 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 measurements 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 ($\text{kg/m}^2$). 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 (Guzmán-Campoy 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 (Leger, Mercier, Gadouy, & Lambert, 1988), which is the cardiopulmonary 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 (Leger et al., 1988). Then, participants were categorized as having a healthy or unhealthy cardiopulmonary fitness profile according to the maximum oxygen uptake cut-off points (Wells, Laurson, Eissenmann, &

### Table 1

<table>
<thead>
<tr>
<th>Reference</th>
<th>Gender</th>
<th>Age (years)</th>
<th>Instruments</th>
<th>Steps</th>
<th>MVPA</th>
<th>Optimal cut-off point (steps/day)</th>
<th>Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adams et al. (2009)</td>
<td>28 males and 28 females</td>
<td>11-16</td>
<td>Actigraph 7164</td>
<td>Uncensored</td>
<td>Freedom 3 MEIs &amp; 9 METs</td>
<td>11,714</td>
<td>AUC=.88, TP=.84, TN=.83</td>
</tr>
<tr>
<td>Coley et al. (2012)</td>
<td>283 males and 283 females</td>
<td>6-19</td>
<td>Actigraph 7164</td>
<td>Uncensored</td>
<td>Actigraph</td>
<td>12,000</td>
<td>R=.68</td>
</tr>
<tr>
<td>Adams et al. (2013)</td>
<td>646 males/ 465 females</td>
<td>12-17</td>
<td>Actigraph 7164</td>
<td>Uncensored</td>
<td>Freedom 3 MEIs</td>
<td>11,000,10,500</td>
<td>AUC=.84-85, P&lt;.74-76</td>
</tr>
<tr>
<td>451 males/ 114 females</td>
<td>12-17</td>
<td>Actigraph 7164</td>
<td>Uncensored</td>
<td>Freedom 3 MEIs</td>
<td>14,000,11,500</td>
<td>AUC=.95-90, P&lt;.84-77</td>
<td></td>
</tr>
<tr>
<td>Evenson</td>
<td>13,000,12,000</td>
<td>Freedom 4 MEIs</td>
<td>8,500-7,500</td>
<td>AUC=.90-90, P&lt;.70-70</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Freedom 4 MEIs</td>
<td>11,500-9,000</td>
<td>AUC=.91-91, P&lt;.80-82</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Evenson</td>
<td>10,500-9,500</td>
<td>Freedom 4 MEIs</td>
<td>12,118</td>
<td>AUC=.85, TP=.78, TN=.85</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: MVPA = Moderate-to-vigorous physical activity; AUC = Area under the curve; TP = True Positive fraction; TN = True Negative fraction; specificity; $R = \text{Regression coefficient}$; $P = \text{Proportion of agreement}.$
The 20-minute shuttle run test has demonstrated adequate validity among adolescents (Mayorga-Vega, Aguilar-Soto, & Viciana, 2015; Mayorga-Vega, Bocanegra-Parrilla, Ornelas, & Viciana, 2016). The results of the Mann-Whitney U test showed that adolescents who achieved the daily steps recommendations had 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 (78.100); 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 accelerometer-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.

### 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 some of the variables 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 follows: 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 effect sizes were calculated to examine the magnitude of these comparisons (Field, 2013). Finally, the relative risk or risk ratio (RR), with the 95% confidence 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 analyses 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 < .05.

### Results

From the initial sample of 156 adolescents (87 males and 69 females) who agreed to participate and meet 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 (38.100); 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 (78.100); 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 accelerometer-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 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 < .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
It is worth noting that in the present study the MVPA was defined as co - 4 METs, instead of the 3 METs typically used for adults (Baunegartner 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 & O’Doh, 2008), the 4 METs thresholds have been suggested in order to account for their higher level of resting energy expenditure compared with adults (Harrell, 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, & O’Doh, 2008). In this line, although accelerometer-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 meet the 11,000/10,500 and 13,500 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 meet a healthy cardiorespiratory fitness level, meanwhile the percentage of male adolescents was similar to the nationally representative sample in Chile (49% and 45%, respectively) (Cortez-O’Ryan & Aguilar-Farias, 2017), in the present sample the percentage of females reaching the healthy zone was considerably higher (38% vs. 16%, respectively) (Cortez-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...
Additionally, because of the small number of participants in some studies. Due to the low number of participants, potentially different results based on small samples is simply less generalizable than in large-sized studies related to the relatively small sample. Examining the cross-validation 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 devices 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 accuracy of 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, accelerometer-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 higher 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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**References**


