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Concurrent validity of the ActiGraph GT3X+ and activPAL for assessing sedentary behaviour in 2-3-year-old children under free-living conditions

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Abstract

Objectives

ActiGraph accelerometer cut-points are commonly used to classify sedentary behaviour (SB) in young children. However, they vary from 5counts/5 s to 301counts/15 s, resulting in different estimates and inconsistent findings. The aim was to examine the concurrent validity of ActiGraph GT3X + cut-points against the activPAL for measuring SB in 2–3-year-olds during free-living conditions.

Design

Observational validation-study.

Methods

Sixty children were fitted with the activPAL and ActiGraph simultaneously for at least 2 h. Nine ActiGraph cut-points ranging from 60 to 1488 counts per minute were used to derive SB. Bland & Altman plots and equivalent tests were performed to assess agreement between methods.

Results

Estimates of SB according to the different ActiGraph cut-points were not within the activPAL ±10% equivalent interval (-4.05; 4.05%). The ActiGraph cut-points that showed the lower bias were 48counts/15 s (equivalence lower limit: $p = 0.597$; equivalence upper limit: $p < 0.001$; bias: -4.46%; limits of agreement [LoA]: -21.07 to 30.00%) and 5counts/5s (equivalence lower limit: $p < 0.001$; equivalence upper limit: $p = 0.737$; bias: -5.11%; LoA: 30.43 to 20.20%). For the 25counts/15s, 37counts/15s and 48counts/15s ActiGraph cut-points, the upper limits were within the equivalent interval ($p < 0.001$) but not the lower limits ($p > 0.05$). When using the 5counts/5s and 181counts/15s ActiGraph cut-points, lower limits were within the equivalent interval ($p < 0.001$) but not the upper limits ($p > 0.05$). Confidence intervals of the remaining ActiGraph cut-points lie outside the equivalent interval.

Conclusions

Although none of the ActiGraph cut-points provided estimates of SB that were equivalent to activPAL; estimates from 48counts/15 s and 5counts/5 s displayed the smallest mean bias (˜5%).

Keywords

2-3-year-old, children, free-living, concurrent, validity, conditions, actigraph, under, gt3x+, activpal, assessing, sedentary, behaviour

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Conclusions

Although none of the ActiGraph cut-points provided estimates of SB that were equivalent to activPAL; estimates from 48counts/15s and 5counts/5s displayed the smallest mean bias (~5%).

Keywords: Toddler; Sitting Time; Activity Device; Equivalence.

Introduction

Advances in understanding behavioural epidemiology of sitting or sedentary behaviour (SB) are, in large part, due to advances in activity monitor technology [1], which address several of the limitations associated with self- or parent-report measures [2]. Accelerometery-based activity monitors that collect time-stamped posture and activity information are becoming increasingly affordable [3] and have showed adequate validity in young children [4-6]. Objective devices allow the quantification of overall levels of sedentary time over entire days or during specific segments of the day, such as during childcare-hours. Objective measures are therefore, ideal for investigating levels and patterns of SB in young children, given their precision and because they do not rely on recall memory.

There are several accelerometers available to measure SB or sitting time in young children. The ActiGraph (ActiGraph. Pensacola, Florida, USA) is typically worn on the right hip and is the most commonly used activity monitor in studies with children. This monitor is valid, reliable and feasible to use in children as young as 2-years [5-8]. Nevertheless, the accuracy of the available sedentary ActiGraph cut-points for toddlers is still debatable. Some cut-points have been validated for toddlers [7-9]; however, others that have been validated for pre-schoolers are also used in toddlers [10-13]. Methodologies to develop cut-points in young children varied. Different age groups, samples sizes, activity protocols or criterion measure might result in considerable differences in estimates of SB [14, 15]. The ActiGraph SB cut-points for young children range from 5counts/5s [8] to 301counts/15s [16]. Thus, compare outcomes between studies is challenging.

In a validation and cross-validation study, Trost et al. [7] compared several ActiGraph SB cut-points on 18 toddlers that were videotaped during 20min while wearing the accelerometer. Results indicated that lower cut-points might provide more accurate measures of SB than higher cut-points. However, the short duration of observation in that study resulted in children spending only 2min (10%) of time in SB and so, further research with larger periods of SB are needed to confirm which cut-points might be most suitable in 2-3year-olds. Another issue of hip-mounted accelerometer (and respective cut-points) is the difficulty in distinguish standing still from sitting [15]. Unlike this typical method, activPAL (PAL technologies ltd. Glasgow, UK) is fitted on the thigh and classifies SB based on the angle of the limb, overcoming this limitation and providing more accurate estimates of SB in children than several other objective monitoring approaches [17]. This device has been validated in children [17-20].

Thus, the aim of this study was to examine the concurrent validity of hip-mounted ActiGraph GT3X+ cut-points with the thigh-mounted activPAL for measuring SB in 2-3-year-olds under free-living conditions.

Methods

Participant data were collected as part of the *Get-Up! Study* [21]. Data for the present report was gathered at follow up (2017) in 60 healthy 2-3-year-olds (50% boys) aged 22 to 42 months. Of the 242 young children observed on the follow-up data collection, 33 were not compliant with wearing one or both devices and 149 had less than two hours of monitoring for both devices simultaneously, and were therefore, excluded from the current analyses.

The *Get-Up! Study* was approved by the University of Wollongong's Human Research Ethics Committee (HE15/236), conducted in accordance with the Helsinki Declaration for Human Studies and registered in the Australian and New Zealand Clinical Trials Registry (ACTRN12616000471482, 11/04/ 2016, retrospectively registered). Parents or guardians of the participating children gave informed written consent.

Participating 2-3-year-olds wore the activPAL and ActiGraph GT3X+ simultaneously for one day. They were fitted both devices simultaneously when they arrived at their childcare centre. At the end of the day, prior to leaving the childcare centre the activPAL was removed (and the ActiGraph was left on the child to be used for 24h/day over 7 consecutive days). Activity logs were used to record valid monitoring time as well as nap times. Both devices were initialized to start monitoring at the same time and the placement time of both monitors was recorded by a research team member, whereas nap times (where applicable) and the monitoring end times for each day were recorded by an educator on an activity log. Educators were instructed to avoid removing the devices, except for water-based activities. Educators were also asked to encourage children to wear both devices and keep them on throughout the day.

ActiGraph: Levels of SB over a usual week were measured using ActiGraph GT3X+ accelerometers. ActiGraphs are small, light and unobtrusive devices worn on a belt around the waist. These accelerometers have established validity and utility in young children [5, 7]. These devices collected very high frequency raw data (30 Hz) and were reintegrated into different epochs and analysed according to specific cut-points (supplementary material - Table S1).

activPAL: In the current study, this device was used to capture total time spent sitting/lying during the period that children attended the childcare centre. The activPAL is a small (53 x 35 x 7mm) and lightweight (15g) device, placed on the front of the right thigh (using a small hypo-allergenic adhesive gel patch and covered with a sticky film to secure it) allowing it to measure different postures (i.e. sitting and standing). For the preschool age group under free living conditions this device had acceptable validity, practical utility and reliability for measurement of posture and activity [4]. On a study with thirty pre-schoolers, the median sensitivity for activPAL sit/lie was 92% (interquartile range (IQR): 76.1% - 97.4%; minimum: 44.7%), specificity was 97.3 (IQR: 94.9% - 99.2%; minimum: 88.3%) and positive predicted value was 97.0% (IQR: 91.5% - 99.1%; minimum 83.8%). On an individual child basis, the median onscreen time spent in sit/lie was 43% (IQR = 30.2 – 50.9%) and activPAL underestimated total time spent sitting compared to direct observation (mean difference: 4.4%; paired test, $p<0.01$) [4]. With a sample of forty 4-6-year-olds this device has shown to be a valid measurement tool for discriminating between different postures (categorized as sit/lie, stand or walk) in young children, based on the thigh movement/acceleration [22]. Good accuracy for sit/lie between activPAL and direct observation (ROC-AUC = 0.84), and mean difference of 5.9 (95% confidence interval: 0.6 – 11.1%) was reported, and no significant difference was found between the activPAL predicted time spent in sit/lie and direct observation defined time in sit/lie ($p=0.58$) [22].

ActiGraph data files were visually inspected minute by minute, considering the activity logs and the inclinometer function in order to identify nap(s). Nap beginning was initially located when a change in the accelerometer output from the sitting or standing position to the lying or off position was detected [23], which should roughly agree with the nap times registered in the activity logs. Non-wear time recorded on the activity Log was erased from the file. Data prior wearing the acticPAL and data after removing it was erased from the ActiGraph files. Nap and non-wear times from ActiGraph files were applied to activPAL files. Participants had to have at least 2 hours of simultaneous monitoring to be included in the analysis.

After these processes, each participants' Actigraph and activPAL data were checked to assure they were worn simultaneously (i.e., data matched for day and time). When data from both devices did not match, the participant was excluded from analyses. Using synchronised data, the percentage of time spent in SB was calculated (Actilife Data Analysis software v6.12.1) for ActiGraph according to different established cut-points that were validated for toddlers (5counts/5s (Costa) [8]; 48counts/15s (Trost) [7] and 181counts/15s (Kelly) [9]) or were validated for older children and then applied to toddlers (25counts/15s (Evenson) [10]; 37counts/15s (Pate) [11]; 200counts/15s (Pate) [11]; 1100counts/60s (Reilly) [12]; 301counts/15s (Sirad) [16]; 372counts/15s (Van Cauwenberghe) [13]). The activPAL software v7.2.37 and a processing macro were used to calculate the percentage of time spent sitting captured by the activPAL device.
This project also collected demographic data such as, body mass index (BMI), waist circumference, height, sex and age, using standardized protocols and procedures, as described elsewhere [21].

Descriptive statistics were calculated for all variables, as means and standard deviations (SD). Bland & Altman plots [24] were used to assess differences between methods (bias) and limits of agreement (LoA) between ActiGraph cut-points and activPAL estimates of sitting time at the individual level. Bias were checked for normal distribution with Kolmogov-Smirnov tests. As all differences were normally distributed, no variable transformations were performed and therefore, Bland & Altman plots assumptions were verified.

The equivalence of SB estimates between different ActiGraph cut-points and sitting time given by activPAL was examined at the group level using the 95% equivalence test [25]. Methods were considered equivalent if the 90% confidence interval (CI) for the estimate of SB from ActiGraph cut-point entirely fell within the predefined equivalence region of ±10% of the average percentage of time spent in SB assessed by the activPAL [25]. Descriptive statistics and Bland & Altman analyses were conducted on SPSS 25.0. Equivalence test were performed on SAS (version 9.3 SAS Inc.). Statistical significance was set at $p<0.05$.

Results

Descriptive characteristics of the young participating are presented in (supplementary material - Table S2). Thirty boys and 30 girls were included. The majority of the sample was normal weight (93%). Regarding wear time, 2-3year-olds wore both devices, on average, for 4.1h ± 1.2h (range = 2.3h to 7.0h).

Please insert **figure 1** around here.

The 95% Limits of agreement and respective Bland and Altman pots can be seen on figure 1.

Please insert **Figure 2** around here.

Estimates of SB according to the different ActiGraph cut-points were not within the activPAL ±10% (Fig. 2) equivalent interval (-4.05; 4.05%). The ActiGraph cut-points that showed the lower bias were 48counts/15s (equivalence lower limit: $p = 0.597$; equivalence upper limit: $p < 0.001$; bias: -4.46%) and 5counts/5s (equivalence lower limit: $p < 0.001$; equivalence upper limit: p = 0.737; bias: -5.11%). For the 25counts/15s, 37counts/15s and 48counts/15s ActiGraph cut-points, the upper limits were within the equivalent interval ($p < 0.001$) but not the lower limits ($p > 0.05$). When using the 5counts/5s (and 181counts/15s ActiGraph cut-points, lower limits were within the equivalent interval ($p < 0.001$) but not the upper limits ($p > 0.05$). Confidence intervals for SB from other ActiGraph cut-points were outside of the equivalent interval. To consult *p* values and 90% CI please see table 1.

Please insert **Table 1** around here.

Discussion

Although none of the hip-mounted ActiGraph cut-points used to define SB in 2-3-year-olds were equivalent to activPAL siting time, estimates of SB derived from the 48counts/15s [7] and 5counts/5s [8] cut-points overlapped the equivalence region and provided estimates with the smallest mean bias (~5%). While the cut-points of 25counts/15s, 37counts/15s and 181counts/15s also provided estimates of SB that overlapped the equivalence region derived from activPAL estimates, the mean bias from these cut-points was larger (-7.95 to 8.15%). As such, ActiGraph cut-points slightly greater than 48counts/15s or slightly smaller than 5counts/5s are expected to provide group-level estimates of SB in 2-3-year-olds that are similar to estimates of sitting from activPAL. However, All LoAs were wide, and even the most accurate cut-points underestimated SB by 21% relative to activPAL for some individuals and overestimate by 30% for other individuals. As such, even the most accurate cut-points still included considerable error at an individual level.

Our findings are somewhat different to another study comparing ActiGraph SB cut-points in toddlers. Using direct observation as the criterion method and a 2h observation period, Trost et al. [7] derived a toddler specific cut-point (48counts/15s) for SB and compared it to those previously established for pre-schoolers (when this paper was published the cut-point 5counts/5s [8] had not been validated yet). In the cross-validation sample, all cut-points significantly overestimated SB, with the lowest cut-points, stopping at 25counts/15s [10], providing the least biased estimates. In the present study the 48counts/15s [7] cut-point not only performed better than lower cut-points, but also underestimated the results from activPAL sitting time. Studies in pre-schoolers suggest that, relative to direct observation, activPAL might slightly over-estimate (45.6% vs 45.2%) [22], or underestimate SB (40.8% vs 45.3%) [4]. Consequently, the differences in findings between our study and Trost et al's research might be, in part, due to differences in the criterion methods used. It is possible that activPAL overestimates SB in relation to direct observation. Therefore, our findings suggest that the cut-points of 48counts/15s or 5counts/5s provide estimates of SB that exhibit the least bias, relative to the activPAL, in 2-3-year-olds. However, alternative cut-points may provide more accurate estimates of SB relative to direct observation, and further research is needed to investigate this.

Similarities between study methodologies may be the reason why 48counts/15s [7] and 5counts/5s [8] displayed similar and superior performance in the current study. Both Trost et al. [7] and Costa et al. [8] developed and cross-validated their respective cut-points among toddlers under free-living conditions, rather than using structured activities. These observations of free-living sessions might be expected to be similar to the daily activities and routines that 2-3-year-olds undertake on a typical day – as was the context of our study. Likewise, in both studies, the ActiGraph cut-points were tested against direct observation using the same observation protocol – the Children's activity Rating Scale (CARS) [26]– which may have also contributed to similarities in the findings for these two cut-points.

Despite the similarities in performance between these two cut-points, the 48counts/15s [7] cut-point underestimated (-4.46%) the amount of time spent in SB, whereas 5counts/5s [8] ActiGraph cut-points overestimated the time spent SB (+5.11%), when compared to sitting time measured by the activPAL. Some evidence indicates that the epoch length selected may influence the estimation of SB from the Actigraph, with shorter epoch lengths for the same cut-points increasing the SB estimate [27, 28]. The epoch length used by Costa (5s) [8] was the shortest of all cut-points, which might have contributed to the overestimation of SB despite the lower count threshold used. In contrast, cut-points developed for 15s epochs, such as 48counts/15s [7], 37counts/15s [11] or 25counts/15s [10] underestimated SB relative to activPAL sitting time. For these three cut-points, lower count thresholds increased the bias between methods, and a threshold of slightly higher than 48counts/15s appeared to provide estimates of SB that were similar to those from the activPAL. The remaining cut-points with higher thresholds (181counts/15s [9], 200counts/15s [11], 1100counts/60s [12], 301counts/15s [16], 372counts/15s [13]) resulted in an overestimation of SB.

Although beyond the scope of this study, it is worth noting that the cut-point selected as well as the epoch length chosen can influence the accuracy of accelerometer-based assessments of movement behaviours. The existence of multiple sets of intensity related cut-points for the same age group inhibit an accurate research effort to quantify, understand and intervene on SB. The lack of consensus on cut-point selection and the constant development of new ones for the same population lead to what has been referred in the literature as the cut-point conundrum [29]. The 15s epoch and associated cut-points are the most widely used with young children. Shorter epochs may be more accurate for capturing vigorous physical activity which typically occurs in short bouts but may over-estimate SB because standing relatively still, which may occur in longer bouts than vigorous physical activity, may be mis-classified as sitting. As such, the use of cut-points developed for 15s epochs, while not perfect, may continue to provide an acceptable trade-off for simultaneously capturing SB and moderate-vigorous physical activity.

The sample of 60 children, evenly distributed by sex, is a relatively large sample for activity monitor validation studies, particularly in the early years, and it should be considered a strength of this study [7, 8]. Although the direct observation may be a better criterion measure it is not practical to use over a moderate length of observation with moderate sample size; therefore, the use of thigh-mounted activPAL which arguably provides the most accurate estimate of SB in children relative to other activity monitoring approaches was also a strength of this study, as is the use of free-living protocol in the childcare centre.

This study is not without limitations. ActivPAL has not been validated in toddlers and the validation studies in pre-schoolers have provided mixed results, suggesting that activPAL might overestimate [22] or underestimate SB [4]. Moreover, the definition of SB consists of two parts, posture and energy expenditure (EE). However, activPAL evaluated only the posture, not the intensity (EE). Therefore, using activPAL, the actual SB time may be shorter than the total sitting/lying time evaluated with this device. This is a limitation of all accelerometer-based field studies in children which are based on acceleration rather than also EE, as EE is difficult to assess in the free-living conditions. Lastly, the sample size (n=60) is considered relatively large for this type of studies, however, the amount of missing data on the present study is a drawback.

Conclusion

None of the ActiGraph hip-mounted cut-points provided estimates of SB in 2-3-year-olds that were equivalent to estimates of sitting time from the activPAL; however, estimates from the points slightly greater than (the best cut-point that underestimated) or slightly smaller than (the best cut-point that overestimated) are expected to provide group-level estimates of SB in 2-3-year-olds that are similar to estimates of sitting from the activPAL. Nevertheless, even the most accurate cut-point could overestimate SB for an individual and underestimate for another one. Therefore, estimates of SB even from the most accurate ActiGraph cut-point may still include significant error.

Practical Implications

- The estimation of SB using ActiGraph cut-points may still include a significant error when compared to activPAL estimations in 2-3-year-olds.
- Estimates of SB calculated with 48 counts/15s or 5counts/5s cut-points are the most similar with the estimates provided by activPAL in 2-3-year-olds.
- In 2-3-year-olds, use other ActiGraph cut-points than 48 counts/15s or 5counts/5s to compare estimates of SB provided by actiPAL should be avoided.

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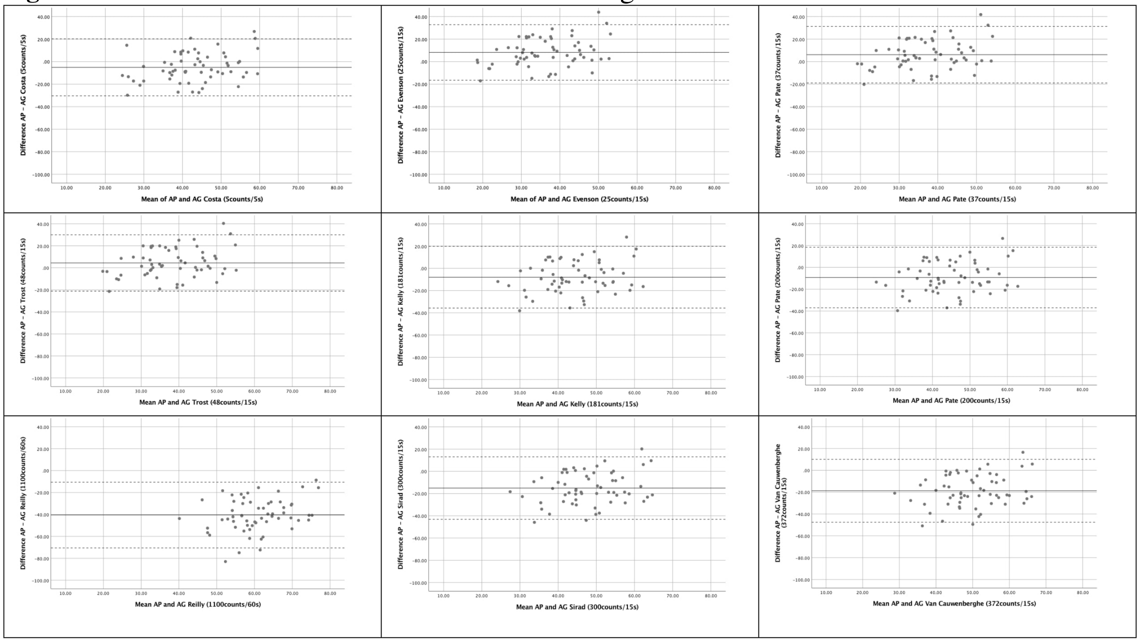
Figure 1. Bland & Altman Plots with 95% limits of agreement.



Footnote Figure 1: Limits of Agreement: 5counts/5s (-30.43 to 20.20); 25counts/15s (-16.50 to 32.80); 37counts/15s (-18.95 to 31.29); 48counts/15s (-21.07 to 30.00%); 181counts/15s (-35.73 to -19.84); 200counts/15s (-37.04 to 18.52); 1100counts/60s (-70.49 to 10.54); 301counts/15s (-43.18 to 13.05) 372counts/15s (-47.54 to 10.11).

Figure 2. 95% equivalence test for accelerometry-based estimated time spent in sedentary behaviours. Times estimated by ActiGraph cut-points are equivalent to activPAL if 90% confidence intervals lie entirely within the equivalence region of direct observation. This figure is a graphical representation of the ActiGraph cut-points estimation in relation to activPAL sitting time estimation. Bias values are symmetrically represented to favour the over/underestimation interpretation.

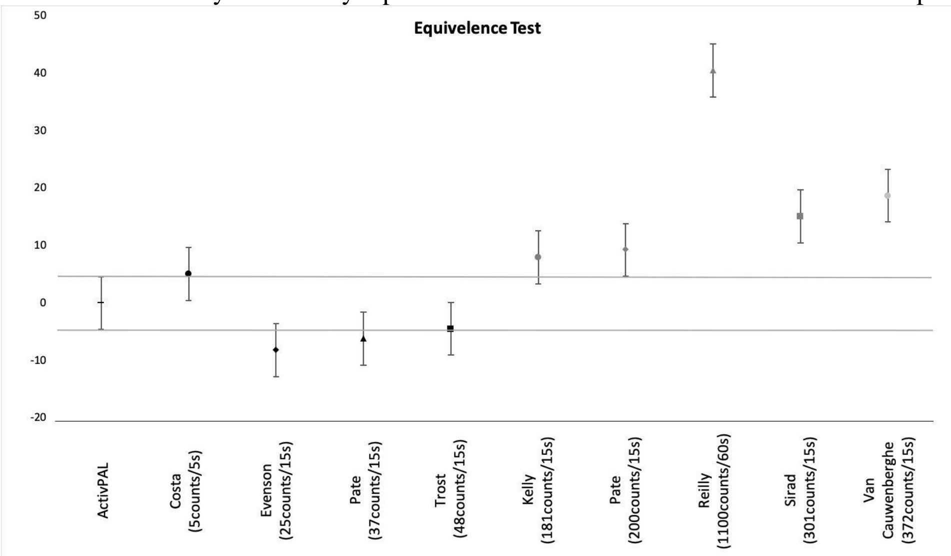


Table 1. Equivalence tests between activPal sitting time and time spent sedentary calculated by the different ActiGraph cut-off points.

Cut-off points	Bias	Mean 90% CI		*p* values	
		Lower	Upper	Lower	Upper
EQUIVALENCE TEST LIMITS (10%)		**-4.05**	**4.05**		
Costa (5counts/5s)	-5.11	-7.90	-2.32	<0.001	0.737
Everson (25counts/15s)	8.15	5.44	10.86	0.993	<0.001
Pate (37counts/15s)	6.17	3.40	8.93	0.897	<0.001
Trost (48counts/15s)	4.46	1.65	7.28	0.597	<0.001
Kelly (181counts/15s)	-7.95	-11.01	-4.89	<0.001	0.981
Pate (200counts/15s)	-9.26	-12.32	-6.21	<0.001	1.000
Reilly (1100counts/ 60s)	-40.52	-43.82	-37.22	<0.001	1.000
Sirad (301counts/15s)	-15.07	-18.16	-11.97	<0.001	1.000
Van Cauwenberghe (372counts/15s)	-18.71	-21.89	-15.54	<0.001	1.000

Supplementary file:

Table S1. ActiGraph sedentary behaviour cut-points for toddlers and pre-schoolers

Author	Cut-off Point	Sample	Criterion Measure	Activities
Costa (2013)	5counts/5s (60cpm)	n = 18 Age: 2-3 y	Direct observation (CARS)	Free play session.
Evenson (2008)	25counts/15s (100cpm)	n=33 Age: 5-8 y	Portable metabolic system	Sit, watch TV, colouring in, slow walk, stair climbing, dribble basketball, brisk walk, bicycling, jumping jacks, running.
Pate (2006)	37counts/15s (148 cpm)	n = 29 Age: 3-5 y	Portable metabolic system	Rest, slow walking, brisk walk and running.
Trost (2012)	48counts/15s (192 cpm)	n = 22 Age: 16-35 m	Direct observation (CARS)	Free play session.
Kelly (2016)	181counts/15s (724 cpm)	n=23 Age: 12-36 m	Direct Observation (CPAF)	Adult-led structured physical activity class.
Pate (2006)	200counts/15s (800 cpm)	n = 29 Age: 3-5 y	Portable metabolic system	Rest, slow walking, brisk walk and running.
Reilly (2003)	1100counts/60s (1100cpm)	n = 30 Age: 3-4 y	Direct Observation (CPAF)	Free play session.
Sirad (2005)	301counts/15s (1204 cpm)	n = 33 Age: 3 y	Direct observation (CARS)	Sitting, sitting and playing, slow walking, fast walking, jogging.
Van Cauwenberghe (2011)	372counts/15s (1488 cpm)	n = 18 Age: 4-6 y	Direct observation (CARS)	Sitting, standing, drawing, walking, jogging at seven speed levels, free play session.

Table S2. Characteristics of the included toddlers.

Characteristics	Mean ± SD
Age (months)	32.5 ± 4.5
Age (y)	2.7 ± 0.4
Weight (kg)	14.8 ± 1.6
Height (cm)	93.5 ± 4.4
BMI (kg/m^2)	16.9 ± 1.3
BMI Category	
Normalweight (n)	56 (93.3%)
Overweight (n)	3 (5.0%)
Obese (n)	1 (1.7%)
Sex	
Boys	30 (50%)
Girls	30 (50%)
Mean wear time (h)	4.1 ± 1.2