ActivPAL™ determined sedentary behaviour, physical activity and academic achievement in college students.

Running title: Patterns of sedentary behaviour, physical activity and academic achievement

Mireia Felez-Nobrega[a*], Charles H. Hillman[b], Kieran P. Dowd[c], Eva Cirera[a] , Anna Puig-Ribera[a]

[a] Sport and Physical Activity Research Group and Centre for Health and Social Care Research, Department of Physical Activity and Sports Sciences, University of Vic - Central University of Catalonia, Vic, Barcelona, Spain: [b]Department of Psychology and Department of Health Sciences, Northeastern University, Boston, MA, USA ;[c]Department of Sport and Health Sciences, Athlone Institute of Technology, Athlone, Co. Westmeath, Ireland

Correspondence about the manuscript should be addressed to Mireia Felez-Nobrega, Carrer Miquel Martí i Pol, 1, 08500, Vic (Barcelona) Spain, phone number: +34661443922; mireia.felez@uvic.cat

Acknowledgements

This work has been supported by the FI-AGAUR Pre-doctoral Research Fellowship Program, Generalitat de Catalunya, 2014FI_B 00339.

ActivPAL™ determined sedentary behaviour, physical activity and academic achievement in college students.

The aim of this study was to examine relationships between activPAL™-determined sedentary behavior (SB) and physical activity (PA) with academic achievement. A total of 120 undergraduates (N=57 female; 20.6 ± 2.3 years) participated in the study. Academic achievement was measured as the grade point average obtained from all completed courses. Participants wore on the right tight an activPAL™ for 7 days to determine total sedentary time, total number of sedentary breaks, sedentary bouts, standing time, light and moderate-to-vigorous physical activity (MVPA). Separate multiple linear regression models were performed to examine associations between SB variables and academic achievement. Light PA, MVPA, total sedentary time, total standing time, or total number of sedentary breaks were not related to academic achievement. Independently of PA, the amount of time spent in sedentary bouts of 10-20min during weekdays was positively related to academic achievement. Given that college students spend the majority of their workday in environments that encourage prolonged sitting, these data suggest that interruptions in prolonged periods of sitting time every 10-20min via short breaks may optimize cognitive operations associated with academic performance.

Keywords: sitting; physical activity; activPAL; cognition; breaks in sitting time.

Introduction

Sedentary behavior (SB), distinct from physical inactivity (Owen, Sparling, Healy, Dunstan & Matthews, 2010), refers to waking behaviours in a sitting or reclining posture that involve an energy expenditure of ≤1.5 METS (Sedentary Behaviour Research Network, 2012). SB has emerged as an important target of health promotion due to its high prevalence in industrialized societies. Most adults spend approximately 54-57% of their total daily waking hours in sedentary pursuits (Healy et al., 2008; Matthews et al., 2008), but prevalence of SB for college students can be markedly higher (Felez-Nobrega, Hillman, Cirera & Puig-Ribera, 2017). Self-report data have indicated that undergraduate students spend 10 hours per day in SB during weekdays, and 7 hours per day during weekend days (Felez-Nobrega et al., 2017). College students spend a considerable amount of time in environments that require long periods of sitting (i.e. universities), contributing to establish long-term SB patterns that persist throughout adulthood (Biddle, Pearson, Ross & Braithwaite, 2010).

While mounting evidence indicates that prolonged sitting time is detrimental to health outcomes (Chastin, Egerton, Leask & Stamatakis, 2015; Hamilton, Healy, Dunstan, Zderic & Owen, 2008), the influence that SB patterns have on cognitive outcomes −including the academic achievement− remains under-investigated and has predominantly focused on school-aged children but not in college students. The most convincing evidence in children has used objective measures of SB or a combination of both objective and subjective measures (Esteban-Cornejo et al., 2015; Haapala et al., 2017; Lopes, Santos, Mota, Pereira & Lopes, 2017; Syväoja et al., 2013). Results from these studies indicate that higher self-reported time spent in doing homework/reading was associated with higher academic

achievement (Esteban-Cornejo et al., 2015), while time spent on specific domains of self-reported SB during leisure-time (e.g. TV watching, Internet surfing, sitting doing nothing) were negatively associated with academic performance (Esteban-Cornejo et al., 2015, Syväoja et al., 2013). Furthermore, evidence of studies employing objective measures (accelerometry) suggest that total/leisure-sedentary time was not associated with indices of academic achievement (Syväoja et al., 2013; Lopes et al., 2017; Esteban-Cornejo et al., 2015).

Academic success is a key determinant in future prospects as better academic achievement can facilitate more opportunities in terms of employment (French, Homer, Popovici, & Robins, 2015). In addition, college academic qualifications play a significant role as they are often considered in personnel selection processes as an indicator of employability value (Cole, Rubin, Field & Giles, 2007). Thus, there is a need to develop a better understanding of the influence that healthy lifestyles −including free living PA and SB patterns− have on academic achievement.

In this context, the primary aim of this study was to examine the relationship between objectively measured SB (total sedentary time, total number of sedentary breaks, and sedentary bouts of different durations) with academic achievement. In addition, as most individuals engage in both PA and SB throughout the day, we further explored whether these associations were independent of light intensity physical activity (LIPA) and moderate-to-vigorous physical activity (MVPA). A secondary aim was to investigate the association between PA and academic achievement to place our findings within the context of previous research conducted in children (see Donnelly et al., 2016 for review).

Methods

This study was conducted on a subsample (n=132, 21.2 yrs. SD=2.5) of a previously collected dataset with undergraduate students from the University of Vic-Central University of Catalonia (Northeastern region of Spain) (Felez-Nobrega et al., 2017). The subsample was no different compared to whole sample for demographic variables (age, gender, students' academic major). The overall study was initiated in March 2015, while activPAL^{TM} measures were included in October 2015 to address the aims of the current study. The recruitment procedure has been detailed elsewhere (Felez-Nobrega et al., 2017). Inclusion criteria were: (i) being a native Spanish or native bilingual Catalan-Spanish speaker (i.e. individuals who speak the local official language in addition to Spanish), (ii) possessing no history of neurological disorders, (iii) being free of any medications that influences the central nervous system and (iv) not having suffered a recent physical injury thus having the capability to be physically active. Ethical approval was obtained by the institutional research ethics committee. All participants provided written informed consent prior to participation.

Participants' academic scores were measured as the grade point average (GPA) obtained from all completed courses at the time of data collection. Course grades ranged from 5 to 10 (from 'pass' to 'excellent'). Each participant provided their GPA via the official online Student Portal of the Education Services of the University of Vic. For first-year students, who had not yet completed any University coursework at the time of data collection, GPA was obtained by the participant at the end of the academic year by the online Student Portal of the

Education Services. The sample average for the total number of courses was 22.15 (SD; 9.05).

The activPAL3™ micro (PAL Technologies Ltd., Glasgow, UK), weighing 9g and measuring 25x45x5mm, was used to quantify SB and PA during free-living conditions. This device has previously been shown to be a valid measure of body posture and for quantifying SB and PA (An, Kim & Lee, 2017; Dowd, Harrington & Donnelly, 2012a; Kozey-Keadle, Libertine, Lyden, Staudenmayer & Freedson, 2011; Lyden, Keadle, Staudenmayer & Freedson, 2016). The activPAL™ was placed in a small flexible nitrile sleeve to waterproof the device and was attached to participants' right thigh using a transparent film (10 x 10cm of hypoallergenic Tegaderm ™ Foam Adhesive Dressing). Participants were instructed to wear the device for 24h hours per day during a 7-day period. The recording time began at 12am for all participants. During the first session, researchers fit the activPAL™ to participants´ thighs and provided them with four additional dressings in case reattachment was needed. Instructions on how to change the dressings were also provided. Participants were asked to record removal reasons and "other comments" over the 7-day period.

Data were initialized using activPAL Professional Software™ (version 7.2.32) and further processed using Microsoft Excel 2010 (Redmond, WA, USA) and MATLAB (MathWorks®, Natick, MA, USA). The protocol used for data collection and reduction is described in detail elsewhere (Dowd, Harrington, Bourke, Nelson & Donnelly 2012b). Briefly, data were included in the analyses if participants provided a minimum of 4 valid days of recording (including 1

weekend day) (Trost, Pate, Freedson, Sallis & Taylor, 2000). Valid days were defined as a day with ≤4h of non-wear time during identified waking hours. Non-wear time was defined as a period with ≥60min of consecutive zero activity counts. In instances where a non-wear period of ≤4 hours was identified, the waking day was adjusted by subtracting the number of non-wear hours from the total waking day time. Additionally, the amount of time identified as non-wear time was also subtracted from the waking day sedentary time, to ensure that these periods of time were removed from all associated variables.

Total sedentary and standing time was determined from the activPAL^{TM} software output. Total time spent in LIPA and MVPA was determined using previously validated count-to-activity thresholds (Powell, Carson, Dowd & Donnelly, 2016). The activPAL^{TM} output was also used to quantify the total number of sedentary breaks (any transition from a sitting/lying posture to standing; Tremblay et al., 2017); and the amount of time spent in sedentary bouts (a period of uninterrupted sedentary time; Tremblay et al., 2017) of different duration categories (<5min, 5-10min, 10-20min, 20-30min, 30-40min, 40-60min, >60min and >90min).
To standardize waking time, variables were presented as a percentage of waking time (i.e. amount of time spent sitting or lying/waking hours *100) and, as patterns of PA and SB differ in week and weekend days (Ortega et al., 2013), all variables are presented separately as average of weekdays and weekend days. The amount of waking time was calculated by subtracting bedtime from rise time. To estimate bed hours, the first registered non-sedentary epoch each day was identified as the rise time while the last registered non-sedentary epoch followed by an uninterrupted sedentary period (>2h) was identified as the time participants

149 went to bed (Dowd et al., 2012b). Breaks in bed hours (i.e. short breaks between
150 bed time and rise time for visits to the bathroom, to get a drink etc.) were
151 identified by manual examination of the data. Time spent standing, in LIPA or in
152 MVPA during these periods was quantified, and the total daily time spent in each
153 behaviour due to breaks in bed hours was subtracted from the total daily time
154 spent in each behaviour. The amount of time spent in breaks in bed hours was
155 then added to the bed hours, to treat this period as one total bed period.
156
157 Descriptive data for the study sample are presented as means and standard
158 deviations (SD) and medians and interquartile range (IQR) for non-normal
159 distributed variables. Variables were tested for normality using the Kolmogrov-
160 Smirnov test and non-normal variables were log10 transformed. Pearson
161 correlations were conducted to measure the association between PA and SB
162 variables with academic achievement. These correlations were conducted prior to
163 regressions to determine which variables were included in the analysis. Students'
164 academic major did not correlate with any of the independent or dependent
165 variables, thus, data were not adjusted by this factor. Separate multiple linear
166 regression models were performed to examine relationships between sedentary
167 bouts and academic achievement. Initial models were conducted to assess the
168 unique contribution of demographic variables (age and gender, model 0) and
169 sedentary bouts (model 1). Furthermore, model 2 examined relationships between
170 sedentary bouts and academic achievement adjusted for age and gender; model 3
171 additionally included MVPA; and, model 4 was further adjusted for LIPA. No
172 multicollinearity was observed among any of the independent variables (VIF<10
173 and Tolerance>0.10). The levels of association were expressed as standardized

beta coefficients and standard errors to allow easy comparison across different independent variables. R^2 was also reported to indicate the model fit. All analyses were conducted using IBM SPSS Statistics v. 21 (SPSS, Inc., Chicago, IL) and level of significance was set at $p = 0.05$.

Results

Descriptive characteristics of the sample are presented in Table 1. From a total of 132 undergraduate students, 12 participants were excluded from analysis. One participant was excluded due to not being a native Spanish or native bilingual Catalan-Spanish speaker, 2 participants were excluded due to suffering a recent physical injury, 3 participants were excluded due to technical problems with data processing, and 6 participants were excluded because they did not provide the minimum wear requirement for the objective measurement of habitual PA. The final dataset included 120 participants (N=64 women, N=56 men; 20.6, SD; 2.3 years). From the final sample, significant outliers were identified and removed from each specific variable: for total number of sedentary breaks during weekdays (n=2 outliers removed), total number of sedentary breaks during weekend days (n=3), % time spent in bouts of <5min during weekdays (n=1), % time spent in bouts of 20-30min during weekend days (n=2), % time spent in bouts of 30-40min during weekend days (n=6), % time spent in bouts of >60min during weekend days (n=3), % time spent in bouts of >90min during week days (n=16), % time spent in bouts of >90min during weekend days (n=30).

****Table 1 near here****

The average waking time during weekdays was 16.4 hrs (SD 1.3), while for weekend days, the average waking time was 15.1 hrs (SD 1.6). During weekdays, on average, the highest amount of waking time was spent sedentary (65.4%; 10.7 hrs; SD 1.5), followed by 22% of waking time spent standing (3.5 hrs; IQR 1.6), 5.9% in LIPA (1 hr; IQR 0.5), and 5.5% of waking time spent in MVPA (0.9 hrs; IQR 0.6). This pattern was similar during weekend days where on average, the highest amount of waking time was spent sedentary (62.5%; 9.4 hrs; SD 2), 24.5% standing (3.8 hrs; SD 1.4), LIPA accounted for 7.1% of waking time (1 hr; IQR 0.7), and 4.5% of time was spent in MVPA (0.7 hrs; IQR 0.8).

Table 2 outlines Pearson correlations among the main variables. LIPA, MVPA, standing hours, total sedentary waking hours, and total number of sedentary breaks were not correlated with academic achievement (all $p \geq 0.05$). However, the bivariate analysis revealed a weak association between the amount of time spent in sedentary bouts of 10-20min on weekdays with academic achievement ($r = 0.20$, $p < 0.05$; Table 2).

****Table 2 near here****

To further examine these associations and determine whether they were independent of PA intensities, separate regression analyses were conducted and

presented in Table 3. Accumulating sedentary time in bouts of 10-20min during weekdays was positively related to academic achievement across all three models (model 2, p= 0.04; model 3, p= 0.04; model 4, p=0.02). This finding suggests that participants who interrupted their sedentary time during weekdays every 10-20min had better academic achievement scores, after adjusting for PA intensities.

****Table 3 near here****

Discussion

This is the first study to examine free-living patterns of objectively measured SB, which includes total sedentary time, sedentary breaks, and sedentary bouts with academic achievement in university students. Four main findings were identified: (a) the percentage of sedentary time was not associated to academic achievement (b) the total number of sedentary breaks was not associated with academic achievement (c) sedentary bouts of 10-20min during weekdays was positively related to academic achievement (c) neither standing time nor physical activity intensities (LIPA and MVPA) were associated with academic achievement.

The results revealed that the percentage of sedentary time either during weekdays or weekends was not associated to academic achievement. These findings are consistent with previous accelerometer-based studies in children, which found no associations between academic performance (assessed via grade point average or national standardized exams) and ActiGraph determined SB (Lopes et al., 2017;

Syväoja et al., 2013). It should be noted that these devices employ sedentary cut-points, or thresholds, to determine sedentary time. This data should be interpreted cautiously, as sedentary time is estimated based on a lack of ambulation instead of body position. More importantly, these devices are not sufficiently sensitive to distinguish between sitting/lying, and standing time as both behaviors produce <100 counts per minute. This is an important limitation as standing is not considered a SB (Sedentary Behaviour Research Network, 2012). Alternatively, the device employed in our study uses accelerations and highly sensitive proprietary algorithms to accurately quantify body position, providing a more valid indicator of sedentary time and affords the opportunity to accurately distinguish sedentary time from standing time.

The current findings also indicated that while the total number of sedentary breaks was not associated with academic achievement, the manner in which sedentary time was accumulated may be important. That is, accumulating sedentary time in bouts of 10-20min during weekdays was positively related to academic achievement. From these results, we can only speculate that frequent breaks in sedentary time (bouts of <5min) may not lead to optimal engagement in the cognitive activity that is being conducted (e.g. studying) while longer periods of uninterrupted sedentary time (from bouts of 20-30min to bouts of >90min) may lead to cognitive fatigue or less optimal engagement. Clearly, this is speculative given the confines of the collected data. However, a recent pilot study has reported the positive effect of breaking sitting time for counteracting fatigue (Wennberg et al., 2016). This study compared the acute effects of uninterrupted sitting on subjective fatigue and cognition (episodic memory, inhibition and

updating) with breaking sitting time every 30 minutes with light intensity walking. The authors found that fatigue levels were lower at 4 hours and 7 hours compared to the sedentary condition, while no significant differences between conditions were found for cognitive performance (Wennberg et al., 2016). It should be noted that these results arise from a pilot study with a small sample size (19 overweight/obese adults).

Although research examining the effects of sedentary breaks to improve academic achievement is in its preliminary stages, we might speculate that frequent breaks in sedentary time (e.g. every 20 minutes) may be a good "starting point" and may have the potential to improve academic performance by reducing mental fatigue caused by prolonged cognitive engagement. However, there is a need for well-designed interventions or randomised control trials to determine whether such approaches have the ability to improve academic performance. In addition, the fact that the positive association between sedentary bouts of 10-20min with better academic achievement was found during weekdays, but not on weekend days, suggests that university settings may play a key role in promoting breaks in sedentary time to improve academic achievement.

Sustained attention and vigilance decrement processes offer a potential mechanism to explain our findings. Pedagogical research consistently finds that attention degrades after between 10 and 30 minutes on task (Frederick, 1986; Horgan, 2003; Stuart and Rutherford, 1978). In the field of applied ergonomics, a similar phenomenon has been established −the vigilance decrement. In laboratory-based settings, the vigilance decrement refers to the slowing in reaction times or

an increase in error rates as an effect of time-on-task during tedious monitoring tasks as a function of time (Davies & Parasuraman, 1982). Listening to a lecture can be considered a type of sustained attention task and standard lecture formats do induce a vigilance decrement which can ultimately impair learning of the material (Young, Robinson & Alberts, 2009). In order to offset the vigilance decrement in classroom settings, some studies suggest that changing the demands during lectures every 10–15 minutes will contribute to keep students engaged (Horgan, 2003; Wankat & Oreovicz, 2003). In this context, we hypothesized that short interruptions on task performance by breaking sedentary time might lead to eliminate vigilance decrement, improve sustained attention, and ultimately promote better academic performance.

Thus, although future studies are needed to corroborate these findings, the results suggest that the actual length of class sessions that mandate prolonged periods (at least one hour) of uninterrupted sitting time should be questioned, while considering the implementation of sedentary breaks to promote academic performance should be further investigated. Furthermore, sedentary bouts of 10-20min were associated with better academic achievement even after adjusting for PA intensities, suggesting that accumulating sedentary time in bouts of 10-20min was associated with better academic achievement for both active and inactive participants. As such, SB should be considered as a health-related component *per se*, independent of PA. As most individuals engage in both PA and SB, it is important to examine the combined associations between PA and SB with cognitive and academic outcomes.

Our results indicated that time spent in objectively measured MVPA was not associated with academic achievement in college-aged students. Similarly, previous research in children and adolescents indicate that, while self-reported PA is positively associated with academic achievement, there is inconsistency in the results of studies when PA is objectively measured via accelerometry (Marques, Santos, Hillman & Sardinha, 2017). To our knowledge, no previous studies have objectively measured PA and its relation to academic achievement in college students. The few existing studies have used self-reported measures of PA, and while some reported higher academic scores for those meeting PA guidelines (Wald, Muenning, O'Connell & Garber, 2014), other studies reported no associations between PA intensities and academic achievement (Felez-Nobrega et al., 2017). Therefore, there is a need for further research which incorporates high quality objective measures to corroborate our results.

The findings of this study have indicated that neither standing time nor LIPA were associated with academic achievement. These findings are consistent with previous studies using self-reported measures in young adults (Felez-Nobrega et al., 2017). Intervention strategies to reduce sedentary time have emphasized the potential for reallocating time from sedentary to LIPA or MVPA to counteract the deleterious effects of prolonged sedentary time on health (Benatti & Ried-Larsen, 2015; Chastin et al., 2015). Future university-based intervention studies and randomised control trials, which focus on the replacement of sedentary time with standing, LIPA and MVPA, are needed to determine whether changes in these behaviors will have an impact on academic performance.

The present study is not without limitations. Given the cross-sectional design of the study, causal conclusions cannot be inferred. Although we controlled for several covariates, there may be residual confounders that may, at least in part, explain the findings. In addition, while the socioeconomic status is an important confounder in studies conducted in children (e.g. Donnely et al., 2016), in our college sample, the socioeconomic status was not assessed. However, as all participants were recruited from a semi private university, our sample was homogeneous along this variable. The small range of variability in academic achievement scores in the current sample may dissemble possible associations, so further studies are needed to better understand the relationship between different PA intensities and academic achievement in college students. In addition, despite the fact that GPA possesses ecological validity and provides an applied measure of certain aspects of cognition, it may not provide an accurate measure of college students' overall cognitive performance as several factors can influence GPA (e.g., difficulty of the content, subjectivity of evaluation processes, etc.). Moreover, given that participants were sampled from a university setting, caution is urged in generalizing these findings to other populations. Finally, objective monitors do not gather domain specific sitting information and therefore, cannot identify if the cognitive engagement across types of SB influences the relationship between SB and cognitive outcomes (Felez-Nobrega et al., 2017). Future research should endeavor to use activPAL^{TM} measures to examine total sedentary time and patterns of SB, accompanied by activity logs. The strengths of the current study should also be acknowledged. This study used what is currently considered the gold standard objective measure for SB, providing important preliminary evidence of objective associations between free-living patterns of SB and academic

achievement. The study also incorporated both objectively determined LIPA and MVPA in the statistical models, which allows to reflect the natural co-dependency of PA and SB. Lastly, given the importance of maximizing students' academic performance, this is the first study that provides initial evidence that may have implications to further develop university-based interventions.

Conclusions

In conclusion, breaking up sedentary time every 10-20 minutes during weekdays was related to better academic achievement. Given that college students spend the majority of their workday in environments that encourage prolonged sitting, these data suggest that interruptions in prolonged periods of sitting time every 10-20 minutes via short breaks may optimize cognitive operations associated with academic performance. Future experimental research is needed to better explore the characteristics of sedentary breaks to improve academic achievement (e.g. frequency of breaks, interruptions of SB with LIPA or MVPA). In addition, future research should consider examining the impact of sedentary breaks on other aspects of cognition (e.g. attention, cognitive control).

Funding details

This work was supported by the FI-AGAUR Pre-doctoral Research Fellowship Program, Generalitat de Catalunya.

Disclosure of interest

The authors report no conflicts of interest

Ethical approval

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Informed consent was obtained from all individual participants included in the study.

References

An, H.-S., Kim, Y., & Lee, J.M. (2017). Accuracy of inclinometer functions of the activPAL and ActiGraph GT3X+: A focus on physical activity. *Gait & Posture*, *51*, 174–180. https://doi.org/10.1016/j.gaitpost.2016.10.014

Ariga, A., & Lleras, A. (2011). Brief and rare mental "breaks" keep you focused: Deactivation and reactivation of task goals preempt vigilance decrements. *Cognition*, *118*(3), 439-443. http://doi.org/10.1016/j.cognition.2010.12.007

Benatti, F. B., & Ried-Larsen, M. (2015). The Effects of Breaking up Prolonged Sitting Time: A Review of Experimental Studies. *Medicine and Science in Sports and Exercise*, *47*(10), 2053–2061. https://doi.org/10.1249/MSS.0000000000000654

Biddle, S. J., Pearson, N., Ross, G.M., Braithwaite, R. (2010). Tracking of sedentary behaviors of young people: a systematic review. *Preventive Medicine, 51(5):*345–51. https://doi.org/10.1016/j.ypmed.2010.07.018.

Chastin, S. F. M., Egerton, T., Leask, C., & Stamatakis, E. (2015). Meta-analysis of the relationship between breaks in sedentary behavior and cardiometabolic health. *Obesity*, *23*(9), 1800–1810. https://doi.org/10.1002/oby.21180

Cole, M. S., Rubin, R. S., Feild, H. S., & Giles, W. F. (2007). Recruiters' perceptions and use of applicant resume information: Screening the recent graduate. *Applied Psychology, 56*(2), 319–343. https://doi.org/10.1111/j.1464-0597.2007.00288.x

Davies, D. R., & Parasuraman, R. (1982). The psychology of vigilance. London: Academic Press.

Donnelly, J. E., Hillman, C. H., Castelli, D., Etnier, J. L., Lee, S., Tomporowski, P., Lambourne, K., Szabo-Reed, A. N. (2016). Physical Activity, Fitness, Cognitive Function, and Academic Achievement in Children. *Medicine & Science in Sports & Exercise, 48*(6), 1197–1222. https://doi.org/10.1249/MSS.0000000000000901

Dowd, K. P., Harrington, D. M., & Donnelly, A. E. (2012a). Criterion and concurrent validity of the activPAL^{TM} professional physical activity monitor in adolescent females. *PloS One, 7*(10), e47633. https://doi.org/10.1371/journal.pone.0047633

Dowd, K. P., Harrington, D. M., Bourke, A. K., Nelson, J., & Donnelly, A. E. (2012b). The measurement of sedentary patterns and behaviors using the activPAL^{TM} Professional physical activity monitor. *Physiological Measurement*, *33*(11), 1887–1899. https://doi.org/10.1088/0967-3334/33/11/1887

Esteban-Cornejo, I., Martinez-Gomez, D., Sallis, J. F., Cabanas-Sánchez, V., Fernández-Santos, J., Castro-Piñero, J., & Veiga, O. L. (2015). Objectively measured and self-reported leisure-time sedentary behavior and academic performance in youth: The UP&DOWN Study. *Preventive Medicine*, *77*, 106–111. https://doi.org/10.1016/j.ypmed.2015.05.013

449 Felez-Nobrega, M., Hillman, C. H., Cirera, E., & Puig-Ribera, A. (2017). The
450 association of context-specific sitting time and physical activity intensity to
451 working memory capacity and academic achievement in young adults.
452 *European Journal of Public Health*, *9*, 755–62.
453 https://doi.org/10.1093/eurpub/ckx021
454 Frederick, P. J. (1986). 'The Lively Lecture – 8 Variations'. *College Teaching*
455 *34*(2): 43–50. http://dx.doi.org/10.1080/87567555.1986.9926766
456 French, M. T., Homer, J. F., Popovici, I., & Robins, P. K. (2015). What you do in
457 high school matters: High school GPA, educational attainment, and labor
458 market earnings as a young adult. *Eastern Economic Journal*, 41(3), 370-
459 386. https://doi.org/10.1057/eej.2014.22.
460 Haapala, E. A., Väistö, J., Lintu, N., Westgate, K., Ekelund, U., Poikkeus, A. M.,
461 Brage, S., Lakka, T. A. (2017). Physical activity and sedentary time in
462 relation to academic achievement in children. *Journal of Science and*
463 *Medicine in Sport*, *20*(6), 583–589.
464 https://doi.org/10.1016/j.jsams.2016.11.003
465 Hamilton, M. T., Healy, G. N., Dunstan, D. W., Zderic, T., & Neville Owen.
466 (2008). Too Little Exercise and Too Much SittingSitting: Inactivity
467 Physiology and the Need for New Recommendations on Sedentary Behavior.
468 *Current Cardiovascular Risk Reports*, *2*(4), 292–298.
469 https://doi.org/10.1007/s12170-008-0054-8.Too
470 Healy, G. N., Wijndaele, K., Dunstan, D. W., Shaw, J. E., Salmon, J., Zimmet, P.
471 Z., & Owen, N. (2008). Objectively measured sedentary time, physical
472 activity, and metabolic risk: the Australian Diabetes, Obesity and Lifestyle
473 Study (AusDiab). *Diabetes Care*, *31*(2), 369–71.

https://doi.org/10.2337/dc07-1795

Horgan, J. (2003). ‘Lecturing for Learning’, in H. Fry, S. Ketteridge & S. Marshall (eds) A Handbook for Teaching and Learning in Higher Education (2nd edition), pp. 75–90. London: Routledge Falmer.

Kalechstein, A. D., Newton, T. F., & van Gorp, W. G. (2003). Neurocognitive Functioning is Associated with Employment Status: A Quantitative Review. *Journal of Clinical and Experimental Neuropsychology, 25*(8):1186–1191. https://doi.org/10.1076/jcen.25.8.1186.16723

Kozey-Keadle, S., Libertine, A., Lyden, K., Staudenmayer, J., & Freedson, P. S. (2011). Validation of wearable monitors for assessing sedentary behavior. *Medicine and Science in Sports and Exercise, 43*(8), 1561–1567. https://doi.org/10.1249/MSS.0b013e31820ce174

Lam, C. M., & Beale, I. L. (1991). Relations Among Sustained Attention, Reading Performance, and Teachers' Ratings of Behavior Problems. *Remedial and Special Education, 12*(2):40–47. https://doi.org/ 10.1177/074193259101200208

Lopes, L., Santos, R., Mota, J., Pereira, B., & Lopes, V. (2017). Objectively measured sedentary time and academic achievement in schoolchildren. *Journal of Sports Sciences, 414*(April 2016), 1–7. https://doi.org/10.1080/02640414.2016.1172724

Lyden, K., Keadle, S. K., Staudenmayer, J., & Freedson, P. S. (2016). The activPAL TM Accurately Classifies Activity Intensity Categories in Healthy Adults. *Medicine and Science in Sports and Exercise*, In press. https://doi.org/10.1249/MSS.0000000000001177

Marques, A., Santos, D. A., Hillman, C. H., & Sardinha, L. B. (2017). How does

499 academic achievement relate to cardiorespiratory fitness, self-reported
500 physical activity and objectively reported physical activity: a systematic
501 review in children and adolescents aged 6–18 years. *British Journal of Sports*
502 *Medicine.* In press. https://doi:10.1136/bjsports-2016-097361.
503 Matthews, C. E., Chen, K. Y., Freedson, P. S., Buchowski, M. S., Beech, B. M.,
504 Pate, R. R., & Troiano, R. P. (2008). Amount of Time Spent in Sedentary
505 Behaviors in the United States, 2003-2004. *American Journal of*
506 *Epidemiology*, *167*(7), 875–881. https://doi.org/10.1093/aje/kwm390
507 Ortega, F. B., Konstabel, K., Pasquali, E., Ruiz, J.R., Hurtig-Wennlöf, A., Mäestu,
508 J., Löf, M., Harro, J., Bellocco, R., Labayen, I., Veidebaum, T., & Sjöström,
509 M. (2013) Objectively Measured Physical Activity and Sedentary Time
510 during Childhood, Adolescence and Young Adulthood: A Cohort Study.
511 *PLoS ONE 8*(4): e60871. https://doi:10.1371/journal.pone.0060871
512 Owen, N., Sparling, P. B., Healy, G. N., Dunstan, D. W., & Matthews, C. E.
513 (2010). Sedentary behavior: emerging evidence for a new health risk. *Mayo*
514 *Clinic Proceedings*, *85*(12), 1138–1141.
515 https://doi.org/10.4065/mcp.2010.0444
516 Powell, C., Carson, B., Dowd, K., & Donnelly, A. (2016). Simultaneous
517 validation of five activity monitors for use in adult populations.
518 *Scandinavian Journal of Medicine & Science in Sports*. In press.
519 Sedentary Behaviour Research Network. (2012). Letter to the editor: standardized
520 use of the therm “sedentary” and “sedentary behaviors”. *Appl Physiol Nutr*
521 *Metab.*, *37*(3), 540–542. https://doi.org/10.1016/j.mhpa.2012.06.001
522 Stuart, J., & Rutherford, R. J. (1978) ‘Medical Student Concentration During
523 Lectures’. *The Lancet 2*: 514–16.

524 Syväoja, H. J., Kantomaa, M. T., Ahonen, T., Hakonen, H., Kankaanpää, A., &
525 Tammelin, T. H. (2013). Physical activity, sedentary behavior, and academic
526 performance in Finnish children. *Medicine and Science in Sports and*
527 *Exercise*, *45*(11), 2098–2104.
528 https://doi.org/10.1249/MSS.0b013e318296d7b8
529 Tremblay, M. S., Aubert, S., Barnes, J. D., Saunders, T. J., Carson, V., Latimer-
530 Cheung, A. E., Chastin, S. F. M., Altenburg, T. M., & Chinapaw, M. J. M.
531 (2017). Sedentary Behavior Research Network (SBRN) – Terminology
532 Consensus Project process and outcome. *International Journal of Behavioral*
533 *Nutrition and Physical Activity*, *14:75*. https://doi.org/10.1186/s12966-017-
534 0525-8
535 Trost, S. G., Pate, R. R., Freedson, P. S., Sallis, J. F., & Taylor, W. C. (2000).
536 Using objective physical activity measures with youth: how many days of
537 monitoring are needed? *Medicine and Science in Sports and Exercise*, *32*(2),
538 426–31.
539 Wald, A., Muennig, P. A., O'Connell, K. A., & Garber, C. E. (2014).
540 Associations between healthy lifestyle behaviors and academic performance
541 in U.S. undergraduates: A scondary analysis of the American College Health
542 Association's National College Health Assessment II. *American Journal of*
543 *Health Promotion*, *28*(5), 298–305. https://doi.org/10.4278/ajhp.120518-
544 QUAN-265
545 Wankat, P & Oreovicz, F. (2003) 'Breaking the 15-minute Barrier'. *ASEE Prism*
546 *12*(8): 40–2.
547 Wennberg, P., Boraxbekk, C.-J., Wheeler, M., Howard, B., Dempsey, P. C.,
548 Lambert, G., Eikelis, N., Larsen, R., Sethi, P., Occleston, J., Hernestål-

549 Boman, J., Ellis, K. A., Owen, N., Dunstan, D. W. (2016). Acute effects of
550 breaking up prolonged sitting on fatigue and cognition: a pilot study. *BMJ*
551 *Open*, *6*(2), e009630. https://doi.org/10.1136/bmjopen-2015-009630
552 Young, M. S., Robinson, S., & Alberts, P. (2009). Students pay attention!
553 Combating the vigilance decrement to improve learning during
554 lectures. *Active Learning in Higher Education*, *10*(1), 41-55.
555 https://doi.org/10.1177/1469787408100194
556
557