MEASUREMENT ISSUES AND POOR ADJUSTMENTS FOR PHYSICAL ACTIVITY AND SLEEP UNDERMINE SEDENTARY BEHAVIOUR RESEARCH — THE FOCUS SHOULD SHIFT TO THE BALANCE BETWEEN SLEEP, SEDENTARY BEHAVIOUR, STANDING AND ACTIVITY

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Abstract:

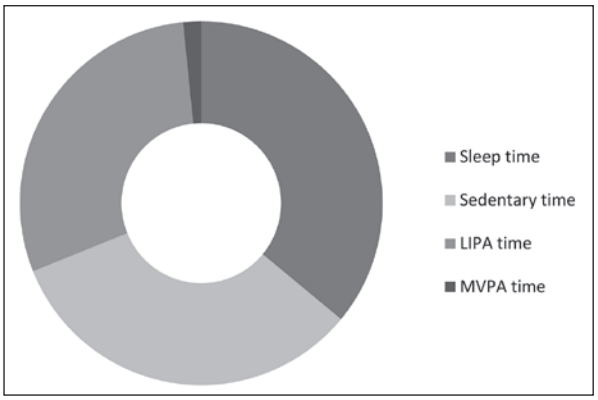
This paper critically appraised 54 recent studies linking sedentary behaviour (SB) and health, specifically regarding their assessment of SB and adjustments for physical activity (PA) and sleep. Almost 90% of the studies collected SB data using self-reports and 59% of these measures had not been previously validated. The majority of studies did not adjust for total PA or for both light-intensity PA (LIPA) and moderate-to-vigorous-intensity PA (MVPA), and a large number of studies did not adjust for all domains of PA. It may, therefore, be that these adjustments were not thorough enough to allow for sound conclusions about the independent associations between SB and health outcomes. Sleep time is also likely to act as a confounding variable in associations between SB and health outcomes. Despite that, only three reviewed studies adjusted their analyses for sleep duration. Evidence presented here casts doubt upon the conclusions about independent associations between SB and health outcomes. Given the facts that: 1) the proportions of time allotted to sleep, SB, standing, LIPA and MVPA are perfectly collinear, 2) all these behaviours may be associated with health, and 3) mutual adjustments between all these variables are needed if their independent contributions to health are to be determined, it seems that investigating the balance between times spent in these behaviours is the next logical step in epidemiological research. This paper, therefore, proposes the *Activity Balance Model (AB model)*; a new theoretical framework for investigating associations of sleep duration, SB, standing, LIPA and MVPA with health outcomes.

Key words: *sleep duration, sedentary behaviour, standing, LIPA, physical activity, Activity Balance Model*

Introduction

Sedentary behaviour encompasses all waking activities in a sitting or reclining posture that require energy expenditure of ≤1.5 METs (e.g. television viewing, passive commuting, occupational sitting) (Sedentary Behaviour Research Network, 2012). The entire 24-hour period of each day is spent in sleep, sedentary behaviour, standing, light-intensity physical activity (LIPA) and moderate to vigorous-intensity physical activity (MVPA). For example, US adults spend on average approximately 36%, 32.9%, 29.5%, and 1.6% of their time at sleep, in sedentary behaviour, LIPA and MVPA, respectively (Bureau of Labor Statistics, 2013; Schuna, Johnson, & Tudor-Locke, 2013). Given the closed nature of a 24-hour block, proportions of time spent in these behaviours are perfectly collinear, that is, every increase in the total time spent in one behaviour necessarily causes a decrease in the total time spent in one or more remaining behaviours (Figure 1). Accordingly, total sedentary time may show significant associations with MVPA (Booth, et al., 2012; Espinel, Chau, van der Ploeg, & Merom, 2014; Healy, et al., 2008; Spittaels, et al., 2012), LIPA (Espinel, et al., 2014; Healy, et al., 2008; Spittaels, et al., 2012), standing (Katzmarzyk, 2014), and sleep time (Booth, et al., 2012; Buman, et al., 2014; Matthews, et al., 2012).

Studies have suggested that prolonged time spent in sedentary behaviours may be an independent risk factor for: [i] type 2 diabetes; [ii] cardiovascular disease; [iii] colorectal, endometrial, ovarian, and prostate cancer; and [iv] cardiovascular, cancer and all-cause mortality (Bauman, Chau, Ding, & Bennie, 2013; Chau, Grunseit, Chey, et al., 2013; Cong, et al., 2014; Ford & Caspersen, 2012; Grøntved & Hu, 2011; Lynch, 2010; Wilmot, et al., 2012). Sedentary behaviours may also be adversely



Legend: LIPA = light-intensity physical activity; MVPA = moderate to vigorous-intensity physical activity
*No data is available on the time spent standing still. Since the data about sedentary, LIPA and MVPA times are taken from accelerometer-based studies, it is possible that the time spent standing is distributed between sedentary and LIPA times.

*Figure 1. Perfectly collinear proportions of time allotted to sleep, sedentary behaviour, LIPA and MVPA in a 24-hour period**

linked to cardiometabolic biomarkers, insulin resistance, hypertension and mental disorders, but limited and mixed results preclude any definite conclusions (Thorp, Owen, Neuhaus, & Dunstan, 2011).

In order to critically appraise these findings, specifically regarding the assessment of sedentary behaviours and adjustments for physical activity and sleep, 54 recent articles were reviewed (Table 1). These articles come from nine systematic and narrative reviews about health outcomes of sedentary behaviour (Bauman, et al., 2013; Chau, Grunseit, Chey, et al., 2013; Cong, et al., 2014; Ford & Caspersen, 2012; Grøntved & Hu, 2011; Lynch, 2010; Thorp, et al., 2011; van Uffelen, Wong, et al., 2010; Wilmot, et al., 2012). To take into account recent changes in the sedentary behaviour definition and paradigm (Pate, O'Neill, & Lobelo, 2008) and the fact that results of most large-scale studies in this area were reported in the last five years (Bauman, et al., 2013), only the articles published since 2008 were included in this review.

Assessment of sedentary behaviour

Most of the reviewed studies assessed television viewing/other screen time (48%), total sedentary behaviour (39%), and occupational sedentarism (22%). Half of the studies on occupational sedentarism were based on the classification according to job type. Non-occupational, transport-related, and leisure-time sedentary behaviour were assessed in 4%, 4%, and 7% of the studies, respectively. These percentages clearly show a lack of studies on health outcomes of most domain-specific (excluding occupational sitting) and type-specific (excluding TV viewing) sedentary behaviours. Specific domains and types of sedentary behaviour should, therefore, be of particular interest in future studies.

Almost none of the studies on TV viewing/screen time specifically asked participants if they were sitting/reclining during these activities. It may be that some participants were standing or exercising instead. Hence, according to the current definition of sedentary behaviour (Sedentary Behaviour Research Network, 2012) these studies can only be tentatively considered sedentary behaviour studies.

Furthermore, 89% of the studies collected sedentary behaviour data exclusively using self-reports, whilst 7% used accelerometers and 4% used heart rate monitors. Self-reports of sedentary behaviour used in 59% of the studies had not been previously validated. In some of these studies, authors reported that measurement properties had been established for a similar sedentary behaviour item/questionnaire. However, from the psychometric point of view, this is not considered acceptable, as even slight changes to the questionnaire may significantly change its measurement properties. Therefore, future studies should either use standardized and validated sedentary behaviour questionnaires or conduct their own psychometric assessment.

Two studies included in this review used heart rate monitors and estimated the time spent in sedentary behaviour as all minutes below the flex HR (Ekelund, Brage, Besson, Sharp, & Wareham, 2008; Helmerhorst, Wijndaele, Brage, Wareham, & Ekelund, 2009). Flex HR is calculated as the mean of

Table 1. Methodology of studies on sedentary behaviour and health with regards to measurement issues and adjustments for physical activity and sleep time

Study	Measure of SB			Adjustments for PA and sleep time	
	Instrument	Domain/type	Validated	PA variables*	Sleep time
Ekelund, et al., 2008	HRM	Total SB (below flex HR)	yes	Total PA assessed by heart rate monitor	no
Howard, et al., 2008	Self-report	Total SB, TV viewing†	no‡	Total PA	no
Inoue, Iso, et al., 2008	Self-report	Total SB	no	Heavy physical work/strenuous exercise, walking/standing, leisure-time sports/exercise	no
Inoue, Yamamoto, et al., 2008	Self-report	Total SB	no	Heavy physical work/strenuous exercise, walking/standing, leisure-time sports/exercise	no

Study	Measure of SB			Adjustments for PA and sleep time	
	Instrument	Domain/type	Validated	PA variables*	Sleep time
Landhuis, Poulton, Welch, & Hancox, 2008	Self-report	TV viewing†	no	no	no
Meyer, et al., 2008	Self-report	TV viewing†	yes	Sport index from Baecke questionnaire	no
Moradi, et al., 2008	Self-report	Occupation type	yes	no	no
Parsons, Manor, & Power, 2008	Self-report	TV viewing†	no	Leisure-time PA	no
Patel, et al., 2008	Self-report	Non-occupational SB	no‡	Recreational MVPA, non-recreational leisure-time PA, exercise	no
Sanchez-Villegas, et al., 2008	Self-report	TV viewing+computer use†	yes	no	no
Ekelund, Brage, Griffin, & Wareham, 2009	Accelerometer	Total SB (<100 cpm)	yes	Accelerometer-based LIPA and MVPA	no
	Self-report	TV viewing†	no		
Gierach, et al., 2009	Self-report	Total SB, TV viewing†	no	no	no
Helmerhorst, et al., 2009	HRM	Total SB (below flex HR)	yes	MVPA assessed by heart rate monitor	no
Katzmarzyk, Church, Craig, & Bouchard, 2009	Self-report	Work+school+home SB	no	Leisure-time PA	no
Krishnan, Rosenberg, & Palmer, 2009	Self-report	TV viewing†	no	Vigorous-intensity exercise, walking for exercise or transport	no
Mathew, et al., 2009	Self-report	TV viewing†	no	Total PA, household activities	no
Mekary, et al., 2009	Self-report	Domestic SB+TV viewing	no	Recreational PA	no
Orsini, et al., 2009	Self-report	Occupation type	yes	Walking+bicycling	no
Tonstad, et al., 2009	Self-report	TV viewing†	no	MVPA	≤6, 7, and ≥8 h/night
Tudor-Locke, Burton, & Brown, 2009	Self-report	Occupational SB	no	Leisure-time MVPA	no
Wijndaele, et al., 2009	Self-report	TV viewing†	no‡	Non-occupational MVPA+occupational walking	no
Dunstan, et al., 2010	Self-report	TV viewing†	yes	Exercise	no
Ford, et al., 2010	Self-report	TV viewing†	no	Physical strain at work, non-occupational PA (walking+gardening+bicycling+sports)	no
Friedenreich, et al., 2010	Self-report	Occupational SB	no	no	no
Gollenberg, et al., 2010	Self-report	Occupational SB, TV viewing†	yes	no	no
Lynch, et al., 2010	Accelerometer	Total SB (<100 cpm)	yes	Accelerometer-based MVPA	no
Patel, et al., 2010	Self-report	Non-occupational SB	no‡	Recreational MVPA+domestic PA	no
van Uffelen, Watson, Dobson, & Brown, 2010	Self-report	Total SB	no‡	Leisure-time MVPA	no
Warren, et al., 2010	Self-report	TV viewing†, riding in a car, sum of both	no	Total PA self-rated in comparison with peers	no
Wijndaele, et al., 2010	Self-report	TV viewing†	yes	Non-occupational MVPA+occupational walking	no
Banks, Lim, Seubsman, Bain, & Sleigh, 2011	Self-report	Total SB, TV viewing+computer games†	no	Exercise-related PA, domestic PA	no
Boyle, Fritschi, Heyworth, & Bull, 2011	Self-report	Occupation type	yes	Recreational PA, heavy/very heavy occupation type	no
Hawkes, Lynch, Owen, & Aitken, 2011	Self-report	TV viewing†	no‡	Non-occupational MVPA+occupational walking	no
Lynch, et al., 2011	Accelerometer	Total SB (<100 cpm)	yes	Accelerometer-based LIPA and MVPA	no
Parent, et al., 2011	Self-report	Occupation type	yes	Sports and/or outdoor activities, occupational PA	no
Stamatakis, Hamer, & Dunstan, 2011	Self-report	Screen time†	no	Occupational PA, non-occupational MVPA	no
Wijndaele, Brage, Besson, Khaw, Sharp, Luben, Wareham, et al., 2011	Self-report	TV viewing†	yes	Total PA	no

Study	Measure of SB			Adjustments for PA and sleep time	
	Instrument	Domain/type	Validated	PA variables*	Sleep time
Wijndaele, Brage, Besson, Khaw, Sharp, Luben, Bhaniani, et al., 2011	Self-report	TV viewing†	yes	Total PA	h/day
Chau, van der Ploeg, Merom, Chey, & Bauman, 2012	Self-report	Occupation type, leisure-time SB	no‡	Leisure-time MVPA, occupational activity type (mostly standing, mostly walking, mostly heavy labor)	no
de Heer, Wilkinson, Strong, Bondy, & Koehly, 2012	Self-report	Work+school+home SB	no	LIPA, MPA, VPA	≤5, 6, 7, 8, 9, and ≥10 h/day
Frydenlund, Jorgensen, Toft, Pisinger, & Aadahl, 2012	Self-report	Leisure-time SB	yes	Total PA	no
Gomez-Cabello, et al., 2012	Self-report	Total SB	no	Walking	no
Koster, et al., 2012	Accelerometer	Total SB (<100 cpm)	yes	Accelerometer-based MVPA	no
Matthews, et al., 2012	Self-report	Total SB, TV viewing†	no‡	Leisure time MVPA	<7, ≥7 h/day§
Pavey, Geeske Peeters, & Brown, 2012	Self-report	Total SB	no‡	Leisure-time MVPA	no
Pinto Pereira, Ki, & Power, 2012	Self-report	Occupational SB, TV viewing†	yes	Leisure-time MVPA	no
van der Ploeg, Chey, Korda, Banks, & Bauman, 2012	Self-report	Total SB	no‡	Non-occupational MVPA+occupational walking	no
Yates, et al., 2012	Self-report	Total SB	yes	MVPA	no
Campbell, Patel, Newton, Jacobs, & Gapstur, 2013	Self-report	Leisure-time SB	no	Recreational PA	no
Chau, Grunseit, Midthjell, et al., 2013	Self-report	Total SB, TV viewing†, Occupation type	no‡	Total PA	no
George, Rosenkranz, & Kolt, 2013	Self-report	Total SB	no‡	Non-occupational MVPA+occupational walking	no
Pulsford, Stamatakis, Britton, Brunner, & Hillsdon, 2013	Self-report	Total SB, occupational SB, TV viewing, non-TV leisure-time SB, leisure-time SB	yes	MVPA, walking, domestic LIPA§	no
Shuval, et al., 2013	Self-report	Total SB, transport-related SB, computer use†	yes	Transport-related MVPA	no
Simons, et al., 2013	Self-report	Occupational SB	no	Occupational PA, walking/cycling for transport, recreational walking/cycling, gardening/doing odd jobs, sports participation	no

Legend: SB = sedentary behaviour; PA = physical activity; LIPA = light-intensity PA; MPA = moderate-intensity PA; VPA = vigorous-intensity PA; MVPA = moderate-to-vigurous intensity PA; HRM = heart rate monitor; Flex HR = mean of the highest resting heart rate and the lowest heart rate during exercise; cpm = accelerometer counts per minute
*Self-reported if not stated otherwise
†The question about TV viewing/screen time did not specifically ask about the body posture during the activity (or the authors did not report so)
‡Authors reported that measurement properties have been established for a similar measure
§The variable was not included in the final model

the individual's highest resting heart rate and the lowest heart rate during exercise, where the resting heart rate is measured in lying, sitting and standing posture (Spurr, et al., 1988). Although this method may give valid estimates of time spent inactive, it does not differentiate between sitting/reclining and standing, and therefore, cannot be used to estimate the time spent in sedentary behaviour. Therefore, the studies by Ekelund et al. (2008) and Helmerhorst et al. (2009) cannot be considered sedentary behaviour studies according to the current definition of sedentary behaviour (Sedentary Behaviour Research Network, 2012). New procedures for data processing need to be developed and validated if

heart rate monitors are to be used in sedentary behaviour research.

All the accelerometer-based studies used the common cut-point of <100 counts per minute to detect the time spent in sedentary behaviour. Due to the inability of hip-mounted accelerometers to differentiate between sitting/reclining while awake or taking a nap, sleep time may be misclassified as the time spent in sedentary behaviour. Besides, fidgeting while seated may cause misclassification of sedentary behaviour with physical activity. When evaluated against activPAL inclinometers as the criterion measure, accelerometer-based individual estimates of sedentary behaviour did not show acceptable accuracy (Aguilar-Farías, Brown, & Peeters, 2013; Healy, et al., 2011; Oliver, Schofield, Badland, & Shepherd, 2010). This measurement issue should be taken into account when interpreting results of accelerometer-based sedentary behaviour studies.

Insufficient resources often limit the choice of sedentary behaviour measures in large-scale studies. Despite that, researchers should endeavour to use direct measures of sedentary behaviour that can differentiate between sitting and standing posture (e.g. inclinometers), or, where more appropriate, self-reported measures of known validity and reliability.

Poor adjustments for physical activity

Total physical activity, LIPA and MVPA may act as confounding variables in associations between sedentary behaviour and health outcomes, because: [i] sedentary behaviour may share as much as 64%, 81% and 25%, respectively, of common variance with these variables (Spittaels, et al., 2012), [ii] well established evidence shows a number of health benefits associated with total physical activity and MVPA (Lee, et al., 2012), and [iii] emerging findings indicate that LIPA may also be associated with different health outcomes (Buman, et al., 2010; Carson, et al., 2013; Friedenreich, Cook, Magliocco, Duggan, & Courneya, 2010; Healy, et al., 2007; Healy, et al., 2008; Pescatello, Murphy, & Costanzo, 2000). Hence, without appropriate adjustments for LIPA and MVPA we cannot draw sound conclusions about independent associations between sedentary behaviour and health.

To demonstrate independent associations between sedentary behaviour and health outcomes, 89% of the reviewed studies adjusted their analyses for one or more physical activity variables. Total physical activity was adjusted in 13%, both non-domain-specific LIPA and MVPA in 7%, and only non-domain-specific MVPA in 11% of the studies. In 39% of the studies analyses were only adjusted for non-occupational physical activity. Out of these studies, 69% assessed only leisure-time physical activities. It is obvious that the majority of studies did not adjust for total physical activity or for both LIPA and MVPA, and a large number of studies did not adjust for all domains/types of activity that can act as confounders in the relationship between sedentary behaviour and health. It may, therefore, be that these adjustments were not thorough enough to allow for sound conclusions about the independent associations between sedentary behaviour and health outcomes.

In 88%, 8% and 4% of the studies the data on physical activity was collected using self-reports, accelerometers and heart-rate monitors, respectively. More than 30% of the studies used self-reported measures of physical activity with unknown validity and reliability. Furthermore, in most of the studies, prior to entering in the analysis, physical activity responses were collapsed to form dichotomous (insufficiently active / sufficiently active) or ordinal-scale variables. This approach neglects the continuous nature of physical activity variables and does not take into account the between-subject variability of physical activity levels within categories. To improve the quality of adjustments for physical activity, where possible and appropriate, such categorizing should be avoided.

When tested against doubly labelled water in free-living conditions, validity (expressed with Spearman's rank correlation coefficients) of self-reported and accelerometer-based measures of physical activity hardly ever exceeds .60 (Helmerhorst, Brage, Warren, Besson, & Ekelund, 2012; Van Remoortel, et al., 2012). This indicates that in most cases less than 36% of valid physical activity variance is measured, while the rest of the variance (64%) is accounted for by the random measurement error and other factors uncorrelated with the true physical activity level. Therefore, when adjusting analyses of the relationship between sedentary behaviour and health outcomes for self-reported or accelerometer-based physical activity levels, researchers only control for a small amount of true physical activity variance. Accordingly, the great portion of unadjusted physical activity variance may have caused residual confounding and led to increased effect sizes and/or false-positive results in the reviewed studies.

There are still no highly valid measures of physical activity suitable for use in large-scale sedentary behaviour research. Therefore, future studies on health outcomes of sedentary behaviour should aim to reduce the amount of unadjusted physical activity variance by using instruments that assess all domains and intensities of physical activity. Additionally, a recent study indicated that the time spent standing may be an independent health-risk factor (Katzmarzyk, 2014). Thus, this variable should also be considered as a potential confounder in the future studies.

No adjustments for sleep duration

Sleep time may act as a confounding variable in associations between sedentary behaviour and health outcomes, because: [i] sleep time and the total time spent in sedentary behaviour may show significant associations (Booth, et al., 2012; Buman, et al., 2014; Matthews, et al., 2012), [ii] sleep duration may show significant associations with television viewing time (Basner, et al., 2007; Matthews, et al., 2012; Wijndaele, Brage, Besson, Khaw, Sharp, Luben, Bhaniani, et al., 2011), [iii] short duration of sleep may be associated with an increased risk of obesity (Cappuccio, et al., 2008), weight gain (Patel & Hu, 2008), type 2 diabetes (Cappuccio, D'Elia, Strazzullo, & Miller, 2010a), prevalent hypertension (Knutson, 2010), coronary heart disease and stroke (Cappuccio, Cooper, Delia, Strazzullo, & Miller, 2011), and all-cause mortality (Cappuccio, D'Elia, Strazzullo, & Miller, 2010b), and [iv] long duration of sleep may be associated with increased risk of type 2 diabetes (Cappuccio, et al., 2010a), cardiometabolic syndrome (Knutson, 2010), cardiovascular disease (Cappuccio, et al., 2011), colorectal cancer (Zhao, et al., 2013), cardiovascular and cancer mortality (Gallicchio & Kalesan, 2009), and all-cause mortality (Cappuccio, et al., 2010b). Hence, without adequate adjustments for sleep duration, erroneous conclusions about independent associations between sedentary behaviour and health may be drawn.

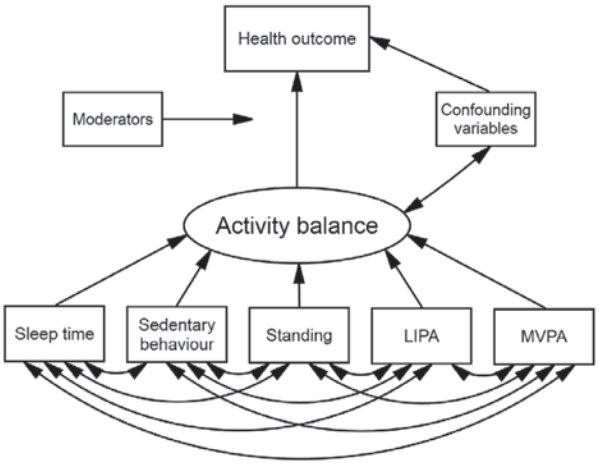
Despite that, no reviewed studies on total sedentary behaviour and only two (8%) reviewed studies on health outcomes of TV viewing/screen time (Tonstad, Butler, Yan, & Fraser, 2009; Wijndaele, Brage, Besson, Khaw, Sharp, Luben, Bhaniani, et al., 2011) adjusted their analyses for sleep duration. Matthews et al. (2012) did not adjust their analyses for sleep duration, because adding this covariate to the model did not change the magnitude of associations by more than 10%. In the other reviewed studies, no clear arguments were provided to justify non-adjustment for sleep time in their analyses. The unadjusted sleep time may have caused residual confounding in these studies and led to increased effect sizes and/or false-positive results. Future studies should, therefore, consider sleep duration as a potential confounding variable.

Activity Balance Model: a new theoretical framework for epidemiological research

Evidence presented here casts doubt upon the conclusions about independent associations between sedentary behaviour and health outcomes. Findings about sedentary behaviour as an independent health risk factor are relatively novel, whilst research about LIPA and standing is in its early phase. It is, therefore, likely that a large number of prior studies about MVPA and health, did not adjust their analyses for sedentary behaviour, LIPA and the time spent standing. The studies about the association between sleep duration and health could also be put under the same scrutiny. Therefore, further research may be needed to substantiate the hypotheses about sleep duration, sedentary behaviour, LIPA, standing and MVPA as health risk factors. To circumvent the issue of insufficient mutual adjustments, it may be necessary that all these behaviours are analysed together in future studies. Hereafter, a new theoretical framework for investigating health outcomes of these behaviours is presented.

The development of the new theoretical framework was motivated by recent hypotheses, and based on previous research findings. Firstly, as stated above, sound evidence shows that both too short and too long duration of sleep may increase health risks. It is suggested that the optimal amount of sleep for adults is on average 7-8 hours per day, although sleep needs may vary substantially between individuals (National Heart Lung and Blood Institute, 2011). Secondly, global authorities call for a minimum of 150 minutes of moderate or 75 minutes of vigorous-intensity physical activity per week, to reduce risk of several negative health outcomes (World Health Organization, 2010). On the other hand, it is hypothesized that excessive physical activity may also be associated with health risks (O'Keefe, Schnohr, & Lavie, 2013; Patil, et al., 2012). Thirdly, although there are still no official recommendations for the total time spent in sedentary behaviour, there are indications that the upper threshold might be set at around seven hours per day (Chau, Grunseit, Chey, et al., 2013). Finally, recent evidence suggests that LIPA (Buman, et al., 2010; Carson, et al., 2013; Friedenreich, et al., 2010; Healy, et al., 2007; Healy, et al., 2008; Pescatello, et al., 2000) and standing (Katzmarzyk, 2014; Qureshi, et al., 2003) may also be beneficial for health, but due to a lack of evidence, no recommendations for these behaviours can be issued.

Given the facts that: 1) the proportions of time allotted to sleep, sedentary behaviour, standing, LIPA and MVPA are perfectly collinear, 2) all these behaviours may be positively and/or negative associated with health, and 3) mutual adjustments between all these variables are needed if their independent contributions to health are to be determined, it seems that investigating the balance between times spent in these behaviours is the next logical step in epidemiological research. Therefore, this paper proposes the *Activity Balance Model (AB model)*; a theoretical framework for investigating associations of sleep duration, sedentary behaviour, standing, LIPA and MVPA with health outcomes (Figure 2).



Legend: LIPA = light-intensity physical activity; MVPA = moderate to vigorous-intensity physical activity

Figure 2. Activity Balance Model (AB model) – a new theoretical framework for epidemiological research

The AB model includes the times spent asleep, in sedentary behaviour, standing posture, LIPA, and MVPA as independent (exposure) variables and a selected health outcome as the dependent variable. When needed, the model can be adjusted for potential confounders and/or stratified by different groups, to account for hypothesized moderating effects. The data needed for empirical studies based on this model can be collected using motion sensors, self-reports, or a combination of both. In the case when the data is not collected using 24-hour continuous monitoring, estimated times spent in different behaviours for each participant need to be linearly rescaled in the way that their sum gives 24 hours. The accelerometer-based data processed using standard cut-points for different intensity levels does not include separate scores for the time spent standing. Such data can also be analysed based on this model, but its incompleteness should be clearly acknowledged. Furthermore, participants may experience problems in recalling the total time spent in LIPA, because it is comprised of a large number of intermittent daily activities that people may not specifically remember. Valid data on the total time spent in LIPA may, therefore, be difficult to collect using self-reports. However, it is possible to indirectly estimate the total time spent in LIPA by subtracting the sum of times/day spent in all other behaviours from 24 hours (possible negative estimates of LIPA should be replaced with 0). Such estimates of LIPA may, however, be biased, because they are inversely related to the magnitude of participants' under- or overestimation of times spent in other behaviours. Furthermore, an augmented AB model may also include the times spent in moderate-intensity and vigorous-intensity physical activity separately, instead of MVPA. Likewise, augmented AB models may also include separate domains of physical activity and/or sedentary behaviour. However, this can only be done if the times spent in the included domains constitute the full duration of the corresponding non-domain-specific behaviour.

The AB model can be used to: 1) investigate the independent and joint associations of the times spent asleep, in sedentary behaviour, standing, LIPA and MVPA with health outcomes, 2) identify the type/s of time allocation to these behaviours that are associated with the highest risk of negative health outcomes, and 3) determine the optimal balance between the times spent in these behaviours to prevent negative health outcomes and achieve health benefits.

The independent variables in the AB model account for the whole 24-hour period (or any other period of time), and, therefore, need to be analysed using statistical analyses for compositional data. Statistical procedures designed for unconstrained data (e.g. isotemporal substitution) are not suitable for analysing compositional data, and may lead to inappropriate inferences. If the data are from 24-hour continuous monitoring (e.g. using wrist worn motion sensors), the independent variables in the AB model will be perfectly collinear and the regression-based analyses for unconstrained data will not run. These analyses would run, if the data are from self-reports and not previously rescaled to form a 24-hour block. However, this is only due to uncorrelated measurement error and does not negate possible collinearity between the true scores in the independent variables. In such cases, it is likely to expect moderate multicollinearity, which is by itself acceptable. Nevertheless, moderate multicollinearity in conjunction with high measurement error (which often characterizes self-reported duration of sleep, sedentary behaviour and physical activity) may lead to wrong inferences (Grewal, Cote, & Baumgartner, 2004; Zidek, Wong, Le, & Burnett, 1996). Therefore, even in the studies based on self-reports, when analysing mutual associations of the times spent asleep, in sedentary behaviour, standing, LIPA and MVPA, statistical methods for compositional data should be preferred.

In conclusion, a number of findings about the independent associations between sedentary behaviour and health are compromised by poor adjustments for physical activity and sleep duration. To circumvent these issues, future studies on health outcomes of sleep duration, sedentary behaviour, standing, LIPA and MVPA should consider using the newly proposed AB model.

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PROBLEMI U MJERENJU I NEADEKVATNA PARCIJALIZACIJA UTJECAJA TJELESNE AKTIVNOSTI I SPAVANJA UMANJUJU VJERODOSTOJNOST ISTRAŽIVANJA SEDENTARNOG PONAŠANJA – TREBALO BI SE PREUSMJERITI NA RAVNOTEŽU IZMEĐU SPAVANJA, SEDENTARNOG PONAŠANJA, STAJANJA I AKTIVNOSTI

U ovome su radu kritički ocijenjena 54 istraživanja o povezanosti sedentarnog ponašanja i zdravlja, pri čemu je fokus na metodama prikupljanja podataka o sedentarnom ponašanju i parcijalizaciji utjecaja tjelesne aktivnosti i vremena provedenoga u spavanju. Gotovo 90% pregledanih istraživanja prikupilo je podatke o sedentarnom ponašanju koristeći anketne metode. Za 59% tih instrumenata prethodno nisu utvrđene mjerne karakteristike. Većina istraživanja nije parcijalizirala utjecaj tjelesne aktivnosti svih razina intenziteta ili ukupne tjelesne aktivnosti, a veći broj istraživanja nije parcijalizirao utjecaj tjelesne aktivnosti u svim domenama. Stoga se može zaključiti da te parcijalizacije nisu bile dovoljno temeljite da bi osigurale donošenje vjerodostojnih zaključaka o nezavisnom utjecaju sedentarnog ponašanja na zdravlje. Vrijeme provedeno u spavanju je također jedan od mogućih čimbenika koji posreduju u povezanosti između sedentarnog ponašanja i zdravlja. Unatoč tome, samo su tri istraživanja uključena u ovaj pregled parcijalizirala utjecaj vremena provedenoga u spavanju. Taj metodološki propust dodatno dovodi u pitanje zaključke o izravnom utjecaju sedentarnog ponašanja na zdravlje. Ako se u obzir uzme: 1) da su udjeli vremena provedenoga u spavanju, sedentarnom ponašanju, stajanju, tjelesnoj aktivnosti niskog intenziteta i tjelesnoj aktinosti umjerenog do visokog intenziteta potpuno linearno zavisni, 2) svi ti oblici ponašanja mogu biti povezani sa zdravljem i 3) međusobna parcijalizacija utjecaja je nužna da bi se utvrdili nezavisni utjecaji tih varijabli na zdravlje, nameće se zaključak da je istraživanje ravnoteže između vremena provedenoga u tim oblicima ponašanjima sljedeći logični korak u epidemiološkim istraživanjima. Stoga je u ovome radu predložen „Activity Balance Model (AB model)“ – novi teorijski okvir za istraživanja zdravstvenih utjecaja vremena provedenog u spavanju, sedentarnom ponašanju, stajanju, tjelesnoj aktivnosti niskog intenziteta i tjelesnoj aktivnosti umjerenog do visokog intenziteta.

Ključne riječi: *spavanje, sedentarno ponašanje, stajanje, tjelesna aktivnost, Activity Balance Model*

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