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Associations between changes in activity and sleep quality and duration over 2 years

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Abstract

Purpose: Insufficient physical activity (PA) and inadequate sleep quality (SQ) and sleep duration (SD) are highly prevalent behaviours that increase the risk of developing many chronic health conditions. Evidence regarding bi-directional relationships between PA, SQ and SD is inconsistent. As changes in one of these behaviours may impact on the other, it is important to understand the nature of the bi-directional relationship between physical activity and sleep. Therefore, the aim of this study was to examine the relationship between changes in physical activity, sleep quality and sleep duration over a 2-year period in middle-aged adults.

Methods: Participants were adults aged 42-72 years from Brisbane, Australia. Mail surveys were used to assess PA, SQ, SD, socio-demographic and health characteristics in 2011 and 2013 (n=3,649). Multinomial logistic regression analyses were conducted to examine the relationships between patterns of change in PA, SQ and SD over the two years.

Results: Improving or maintaining good SQ was associated with increasing or maintaining PA and maintaining PA was associated with maintaining or increasing SQ ($p < 0.05$). Changes in PA were not associated with changes in SD.

Conclusions: A bi-directional relationship between PA and SQ was identified however, no evidence of a relationship in any direction between PA and SD was found. Multi-behaviour interventions targeting both PA and SQ are warranted. Middle-aged adults with poor SQ may benefit from increasing PA and improving SQ may promote higher levels of activity.

Keywords: Exercise; bi-directional associations; mid-aged adults; population sample

Introduction

It is well-established that sufficient physical activity and adequate sleep quality and sleep duration are key elements for preventing and managing many chronic health conditions, including cardiovascular disease, overweight and obesity, type 2 diabetes, depression and anxiety (1, 2). However, internationally, the prevalence of insufficient physical activity and unfavourable sleep behaviours is high. It is estimated that 23.8% (range 4.1-65%.) of the population are insufficiently active (3), 30-50% have poor sleep quality (4), 15-30% have sleep duration below recommended levels, and 8-17% have sleep duration longer than recommended (5, 6). In addition, a high proportion of adults report a combination of low activity, poor sleep quality and sleep duration outside of recommended levels, which is associated with poorer health profiles (7).

A bi-directional relationship between physical activity and sleep has been suggested, such that higher levels of physical activity promote good sleep, and, quality sleep promotes higher physical activity levels (8). Such a relationship could be leveraged in multi-behaviour change interventions and maximise the potential co-action effects of each behaviour on the other (9, 10). Research on this relationship has frequently used data from accelerometers to examine day-to-day patterns in physical activity and sleep. This is useful for understanding these relationships from a short-term perspective, and there is some evidence to support the existence of a bi-directional relationship (11-13). However, several studies have found either a unidirectional or no evidence of this relationship (14-17).

Evidence from two meta-analyses of physical activity interventions has shown that short-term physical activity (typically single bouts) improves sleep onset latency, and longer durations of physical activity (average of 20 weeks) improve sleep quality, efficiency and sleep onset latency (13, 18). In addition, participation in exercise training over 10 weeks to 12 months moderately improves sleep quality (19) and objectively measured reductions in cardio-

respiratory fitness over 2-3 years result in higher odds of developing sleep complaints (20). Furthermore, few intervention studies have examined the associations between physical activity and sleep over extended periods (e.g. >12 months).

Observational studies over longer time periods have reported that insomnia is associated with decreases in physical activity after 5-7 years (21) and reporting consistently high levels of recreational physical activity over the preceding 6 years is associated with better current sleep quality (22). However, the findings are not always consistent, with one study finding that better sleep quality is associated with higher physical activity but physical activity is not associated with sleep quality 2 years later (23).

Health behaviours are influenced by many factors and are prone to change over time, yet few studies have examined how changes in physical activity and sleep behaviours influence changes in each other. Additionally, studies have primarily focussed on how activity influences sleep, but not vice versa (24, 25). Consequently, there is a need to better understand the nature of the bi-directional relationship between physical activity and sleep, and how changes in one behaviour may causally influence the other. Therefore, the aim of this study was to examine the relationship between changes in physical activity, sleep quality and sleep duration over a 2-year period in middle-aged adults.

Methods

Design and Participants

This study used longitudinal data from the HABITAT study, a multi-level study of lifestyle, health and well-being in mid-aged adults (40-65 years) in Brisbane, Australia (26). A full description of the methods can be found elsewhere (26). In 2007, 17,000 individuals (85 randomly selected from each of 200 Census Collection Districts stratified by socioeconomic status) were invited to complete a mail survey every two year. The study was approved by the Queensland University of Technology human ethics committee (QUT ID3967H). Survey

completion was taken as informed consent. The current study used data from the 2011 and 2013 questionnaires, since questions regarding sleep duration, sleep quality and physical activity were included in these survey waves. Of the 11,035 participants who completed the 2007 baseline survey, 6,900 remained in the cohort in 2011, and 6,520 remained in 2013. Only data from participants who returned both the 2011 (wave 3) and 2013 (wave 4) questionnaires (n = 5,795) and had complete data required for the analyses (n = 3,649), were used for the current study.

Physical activity and sleep behaviour

Physical activity (PA) was measured using the Active Australia Questionnaire (AAQ), which assesses time spent walking, and in moderate and vigorous intensity activities during the previous 7 days. The AAQ has been found to have good test-re-test reliability and validity (27, 28). Total weekly physical activity was calculated by summing the time spent in walking, moderate and vigorous intensity activity (excluding gardening), with time in vigorous intensity activity weighted by two to reflect greater intensity. Consistent with recommended scoring protocols, time spent in each of these activities was truncated to 840 minutes and total activity was truncated to 1680 minutes to limit over-reporting (29). Physical activity was classified as: insufficiently active (<150 minutes/week); meeting activity recommendations (150-300 minutes/week); or highly active (>300 minutes/week), consistent with national and international guidelines (30, 31).

Participants rated their sleep quality over the last week using five response options of excellent, very good, good, fair or poor. Responses were collapsed into three categories: excellent (excellent/very good); good (good); or poor (fair/poor).

Sleep duration was assessed by asking participants how many hours they sleep (including at night, naps and any other time during the day) during a usual 24-hour day on each

of weekdays and weekend days. Average daily sleep duration was calculated as a weighted average of reported weekday (weighted by five) and weekend (weighted by two) sleep durations. Sleep duration was subsequently classified using age-appropriate guidelines (7-9 hours for 18-64 years and 7-8 hours for ≥ 65 years) : less-than-recommendations; meeting recommendations; or more-than-recommendations (32).

Patterns of change in physical activity and sleep between 2011 and 2013

Patterns of change in physical activity, sleep quality and sleep duration between 2011 and 2013 were assessed for participants with complete data for all three variables.

The three categories of physical activity were used to create four categories of change in physical activity (Figure 1). Those who were insufficiently active in both 2011 and 2013 were classified as *remained insufficiently active*. Those who were insufficiently active in 2011, and either meeting activity recommendations or highly active in 2013, and those meeting activity recommendations in 2011 and highly active in 2013 were classified as *increased activity*. Those meeting activity recommendations in 2011 and insufficiently active in 2013, and those who were highly active in 2011 and either meeting activity recommendations or insufficiently active in 2013 were classified as *decreased activity*. Those who continued meeting activity recommendations or remained highly active in both 2011 and 2013 were classified as *remained active*.

The three categories of sleep quality were used to create four categories of change in sleep quality (Figure 1). Those with poor sleep quality in both 2011 and 2013 were classified as *maintained poor quality*. Those with poor sleep in 2011 and either good or excellent sleep in 2013, and those with good sleep in 2011 and excellent sleep in 2013, were classified as *increased quality*. Those with good sleep in 2011 and poor sleep in 2013, and those with excellent sleep in 2011 and either good or poor sleep in 2013 were classified as *decreased*

quality. Those who remained in the good or excellent categories in both 2011 and 2013 were classified as *maintained good quality*.

The three categories of sleep duration were used to create four categories of change in sleep duration (Figure 1). Those who reported less-than-recommended or more-than-recommended sleep duration in both 2011 and 2013 were classified as *remained suboptimal*. Those with less-than-recommended or more-than-recommended sleep duration in 2011, and who reported meeting recommended sleep duration in 2013 were classified as *became optimal*. Those meeting recommended sleep duration in 2011 who reported less-than-recommended or more-than-recommended sleep duration in 2013 were classified as *became suboptimal*. Those who reported meeting recommended sleep duration in both 2011 and 2013 were classified as *remained optimal*.

Insert Figure 1 here

Indicators of sociodemographic status and health

Participants reported their date of birth, sex, height, weight, gross annual household income, education, employment status, hours worked, general health, presence of chronic diseases and psychosocial distress. Age in 2011 was calculated from date of birth, and categorised as: 42-54; 55-64; or 65-70 years. Body mass index (BMI) was calculated and categorised as: <25; 25-30; or >30 kg/m². Gross household income (AUD) was collapsed from 13 into five categories: unknown; <\$36,400; \$36,400-\$72,799; \$72,800-\$129,999; ≥\$130,000. Education was collapsed from 10 into three categories: school-only; diploma/vocational; or bachelor degree or higher. Two items were used to assess weekly hours of work. The first item assessed employment status using 10 response options which were collapsed into five categories: full-time; part-time; casual; retired; or not in the workforce (work without pay, home duties, unemployed, permanently unable to work,

student or other). The second item assessed how many hours per week a participant worked in their main job. Weekly work hours were then categorised as: not in the workforce; retired; or 0-35 hours/week, 35.1-40 hours/week or >40 hours/week, for participants who reported being in full-time, part-time or casual employment.

Self-rated health was collapsed from five into three categories: excellent/very good; good; or fair/poor. Participants reported if a doctor or nurse had ever told them they had any of the following chronic conditions: arthritis; asthma; cancer; chronic bronchitis or emphysema; diabetes; heart disease; hypertension; other serious circulatory conditions (e.g. stroke, hardening of arteries); osteoporosis; high cholesterol; injury or depression.

Participants were then categorised as having 0, 1-2 or ≥ 3 chronic conditions. Psychological distress was assessed using the Kessler 6, a validated six item screening questionnaire (33). Respondents were categorised as: no distress (0 -7); or distressed (8-24) (33).

Statistical Analysis

Participant characteristics in 2011 were described using frequencies and proportions. All analyses were adjusted for *a priori* specified covariates commonly associated with physical activity and sleep, and which could confound any relationship between them. These included age, sex, level of education, work hours, BMI, number of chronic health conditions, and psychological distress (34, 35).

Three separate multinomial logistic regression analyses were conducted to determine the relationships between patterns of change in physical activity, sleep quality and sleep duration from 2011 to 2013. Model 1 examined how changes in sleep quality and sleep duration were related to change in physical activity. Model 2 examined how changes in physical activity and sleep duration were related to change in sleep quality. Model 3 examined how changes in physical activity and sleep quality were related to change in sleep duration. The reference

categories for the dependent and independent variables in the models were: *remained inactive*, *maintained poor sleep quality*, and *remained sub-optimal sleep duration*. All analyses were conducted using Stata 12.1 (36)

Results

Of the 3,649 participants included in the analyses, in 2011, the mean age was 55.7 years (SD 7.1), approximately 57% were female, and approximately one third each reported either school-only education or a bachelor degree or higher (Table 1). Mean BMI was 26.9 (SD 5.2), almost one quarter reported three or more chronic conditions and one in eight were categorised as psychologically distressed (Table 1).

In 2011 and 2013, approximately 40% of participants reported insufficient activity or poor sleep quality and nearly a third reported sleep outside recommended durations (Table 2; Figure 1). Figure 1 shows that, despite similar proportions of behaviours being reported at both 2011 and 2013, some participants shifted between categories. One quarter of participants remained inactive, and one third remained active, whilst the remainder either increased or decreased activity. One quarter of participants maintained poor sleep quality, approximately one third maintained good sleep quality, whilst the remainder either increased or decreased sleep quality. For sleep duration, approximately one in five participants remained sub-optimal, three in five remained optimal, whilst the remainder either became either optimal or sub-optimal (Table 2). Overall, 2.66% of participants had insufficient activity, poor sleep quality and sleep duration outside of recommendations in both 2011 and 2013, whilst 9.56% of participants were highly active with excellent sleep quality and recommended sleep duration in both 2011 and 2013.

Insert Table 1 and Table 2 here

Patterns of change in physical activity categories 2011-2013

Associations between patterns of change in sleep quality and sleep duration with patterns of change in physical activity are shown in Table 3. The probability of remaining active (versus remaining inactive) was significantly higher for those whose sleep quality increased (RR=1.38, CI; 1.06-1.80) or remained good (RR=1.42, CI; 1.12-1.81), than those whose sleep quality remained poor (Table 3). The probability of decreasing physical activity (versus remaining inactive) was significantly higher for those whose sleep quality decreased (RR=1.39, CI; 1.03-1.86), than those whose sleep quality remained poor (Table 3). However, patterns of change in sleep duration were not significantly associated with patterns of change in physical activity.

Insert Table 3 here

Patterns of change in sleep quality categories 2011-2013

Associations between patterns of change in physical activity and sleep duration with patterns of change in sleep quality are shown in Table 4. The probability of increasing sleep quality (versus maintaining poor sleep quality) was significantly higher for those who remained active (RR=1.39, CI; 1.06-1.80), or whose sleep duration became optimal (RR=2.23, CI; 1.56-3.17) or remained optimal (RR=3.01, CI; 2.33-3.89), than those in the lowest level of each of their categories (Table 4). The probability of decreasing sleep quality (versus maintaining poor sleep quality) was higher for those who decreased activity (RR=1.39, CI; 1.04-1.88), whose sleep duration became suboptimal (RR=2.23, CI; 1.55-3.21) or remained optimal (RR=3.13, CI; 2.38-4.10), than the lowest level of each of their categories (Table 4). The probability of maintaining good sleep quality (rather than maintaining poor sleep quality) was higher for those who remained active (RR=1.42, CI; 1.12-1.81), whose sleep duration became optimal

(RR=2.58, CI; 1.84-3.61), became suboptimal (RR=2.09, CI; 1.49-2.93) or remained optimal (RR=4.52, CI; 3.55-5.76), than those in the lowest level of each of their categories (Table 4).

Insert Table 4 here

Patterns of change in sleep duration categories 2011 - 2013

Associations between patterns of change in physical activity and sleep quality with patterns of change in sleep duration are shown in Table 5. Patterns of change in physical activity were not significantly associated with patterns of change in sleep duration. The probability of sleep duration becoming optimal (versus remaining suboptimal) was higher for those whose sleep quality increased (RR=2.21, CI; 1.55-3.15) or remained good (RR=2.57, CI; 1.83-3.60), than for those whose sleep quality remained poor (Table 5). The probability of sleep duration becoming suboptimal (versus remaining suboptimal) was higher for those whose sleep quality decreased (RR=2.23, CI 1.55-3.21) or remained good (RR=2.08, CI; 1.48-2.91), than for those whose sleep quality remained poor (Table 5). The probability of maintaining optimal versus maintaining suboptimal sleep duration was higher for those whose sleep quality increased (RR=3.01, CI; 2.33-3.89), decreased (RR=3.13, CI; 2.39-4.10) or remained good (RR=4.51, CI; 3.54-5.74), than for those whose sleep quality remained poor (Table 5).

Insert Table 5 here

Discussion

The aim of this study was to examine the relationship between changes in physical activity, sleep quality and sleep duration over a 2-year period in middle-aged adults, to better understand the nature of the bi-directional relationship between physical activity and sleep, and how changes in one behaviour may influence the other. Bi-directional relationships between changes in physical activity and sleep quality were observed. Remaining physically active was

positively associated with increased sleep quality or maintaining good sleep quality, and maintaining good sleep quality or increasing sleep quality were associated with either remaining physical active or increasing physical activity. Decreases in physical activity and sleep quality were also bi-directionally associated. There was mixed evidence regarding a bi-directional relationship between sleep quality and sleep duration, and no relationship was identified between physical activity and sleep duration. By demonstrating these bi-directional relationships between changes in physical activity and sleep quality in mid-aged adults over two years, our findings improve understanding of the proposed bi-directional relationship between physical activity and sleep.

Maintenance of activity levels at or above recommended levels, or increasing activity, was associated with improved sleep quality, whilst decreasing activity level was associated with a reduction in sleep quality. Maintaining good sleep quality or improvement in sleep quality was associated with maintaining activity levels, whereas reduced sleep quality was associated with decreased physical activity. Hence, both behaviours influence each other both positively and negatively, indicating the presence of a bi-directional relationship. This contrasts with the findings of Youngstedt et al. (14) and Mitchell et al. (15) who found no evidence of a reciprocal relationship between physical activity and sleep, including total sleep time, sleep efficiency, sleep onset latency and WASO. However, the results of the current study are consistent with previous meta-analytical research which observed that increased physical activity was significantly associated with improved sleep quality (13, 19) and other studies which indicated that increasing or maintaining a high level of physical activity was associated with improving or maintaining sleep quality (22, 25).

Additionally, studies have consistently shown benefits of exercise training upon insomnia and sleep apnoea (8, 37). Although this study is unable to identify participants with sleep disorders, given the prevalence of these sleep disorders, the association of increases in

activity on improved sleep quality may be partially explained by this pathway. This study also supports other research indicating better sleep is associated with higher levels of activity (38) and poor sleep is associated with decreased activity (21). The current findings both compare and contrast with another longitudinal study which found sleep quality predicted physical activity but physical activity did not predict sleep quality (23). That study only examined how behaviour at baseline predicted behaviour two years later (23) but did not account for changes in behaviour. It is possible that, by examining changes in behaviour, this study has been better able to identify the bi-directional relationship between physical activity and sleep quality.

This study also found some evidence of a bi-directional relationship between sleep quality and sleep duration. While developing optimal sleep duration was associated with improved sleep quality, developing sub-optimal sleep duration was associated with a reduction in sleep quality. Maintaining optimal sleep duration was also associated with a reduction in sleep quality, which also seems counterintuitive, however this was likely due to it being relative to the group whose sleep duration remained suboptimal, who possibly had poor sleep quality initially, and therefore could not further decrease sleep quality. Maintaining or increasing sleep quality was associated with developing optimal sleep duration, whereas decreased sleep quality was associated with developing sub-optimal sleep duration. Although sleep quality and sleep duration are individual components of sleep, these findings reinforce that they are integrally intertwined from a sleep health perspective (1). Given that both sleep quality and sleep duration, individually influence health (39), this study highlights the importance of optimising each component of sleep to capitalise on any consequent health effects.

The association between decreased sleep quality and the maintenance of optimal sleep duration was also interesting, although it should be interpreted with caution as these results

are relative to those whose sleep duration remained sub-optimal. Further, there was a positive relationship between the development of sub-optimal sleep duration and maintenance of good sleep quality, suggesting that sleep quality and duration do not necessarily change in parallel. These findings are also consistent with previous research in this cohort, demonstrating that these behaviours cluster together in different patterns (7).

This study found no relationship between physical activity and sleep duration which is in contrast to one study which found higher activity levels were associated with a decrease in total sleep time (40). However, relatively few participants reported long sleep duration and a large proportion reported sleep within the recommended duration. This may have reduced the potential to observe relationships between sleep duration and physical activity in the current study.

Limitations for the current study include the relatively small proportion of participants reporting longer sleep durations. This may not have allowed the detection of meaningful relationships between change in sleep duration and physical activity to be observed. Also, this study does not allow for conclusions to be drawn about the day-to-day relationships between behaviours, however health effects associated with these behaviours generally develop over the long term, and are therefore more likely to be associated with the long-term trends in behaviours observed in this study. The current study did not assess the presence of sleep disorders, or how the presence of a sleep disorder influenced results. Future studies are encouraged to consider these factors to better understand these relationships. Measurement of sleep quality only assessed subjective satisfaction which did not allow other aspects of sleep quality (e.g., sleep onset latency and sleep efficiency) to be assessed in this study. Additionally, sleep duration included day-time naps which should be considered when interpreting these findings.

Strengths of the study include the large sample and the longitudinal nature of the study. Furthermore, this study extends previous research of the bidirectional relationship between physical activity and sleep by including both quality and duration and, the study is uniquely comprehensive in examining change in all three behaviours in all directions (i.e., no change, as well as positive and negative changes). Another strength of the current study involves the range of covariates included in the analyses given their potential substantial association between each with the behaviours (e.g., chronic disease and physical activity, sleep quality and sleep duration).

The bidirectional relationships identified by this study, may have important implications for multiple behaviour interventions, as interventions targeting physical activity and sleep could leverage any bidirectional relationships to enhance behaviour change (9, 10). This also has potential implications for health, given that both behaviours influence many similar health conditions (1, 2) and that multiple behaviour interventions provide greater health benefits than single behaviour interventions. The design of this study, which has examined the influences of *changes* in behaviour, is particularly useful for elucidating the potential value of simultaneous interventions targeting physical activity and sleep quality, since it showed that positive changes in one behaviour lead to positive changes in the other.

In conclusion, this study identified bi-directional relationships between physical activity and sleep quality. The findings regarding the relationship between sleep quality and sleep duration were mixed and no relationship between physical activity and sleep duration was identified. Physical activity and sleep quality could be targeted simultaneously in multi-behaviour change interventions, to maximise improvements in activity and sleep and the associated health benefits. Middle-aged adults with poor sleep quality may find improvements to their sleep quality from increasing activity levels and, improving sleep quality may promote higher levels of activity.

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Contributors

ATR, MJD, EGH, WJB, RCP and NWB conceptualised the study. EGH, MJD, NWB and ATR devised the analyses plan. ATR conducted the analyses and wrote the first draft of the manuscript. EGH reviewed the analyses. ATR, MJD, EGH, WJB, RCP and NWB contributed to data interpretation and reviewed, edited and approved the final manuscript.

Conflicts of Interest

There are no professional relationships with companies or manufacturers who will benefit for the results of the present study. The results of this study do not constitute an endorsement by ACSM. The authors declare that the results of the study are presented clearly, honestly and without fabrication, falsification or inappropriate manipulation.

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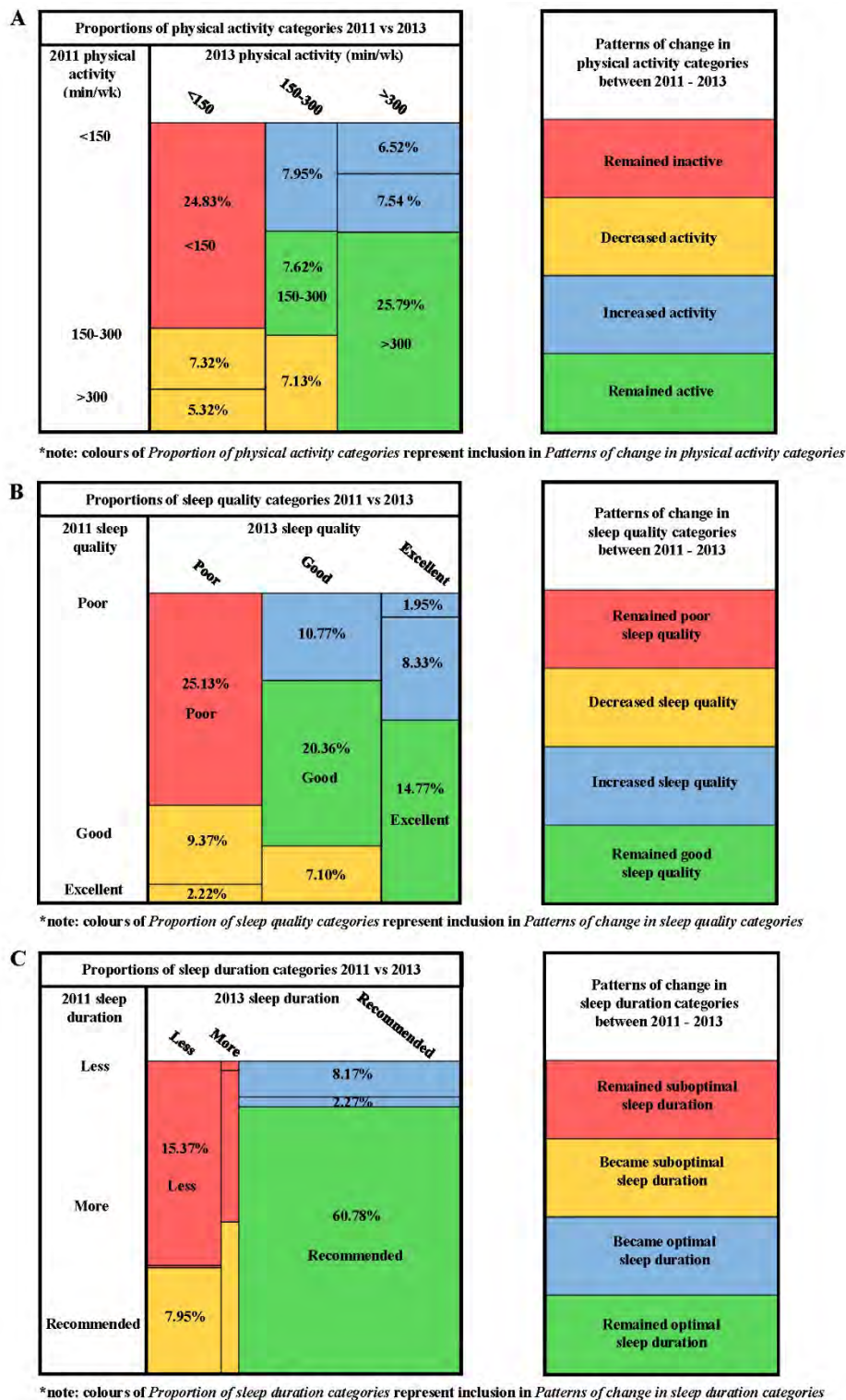


Figure 1. Proportions of physical activity, sleep quality and sleep duration 2011 vs 2013 and behavioural patterns of change between 2011 and 2013 categories for A) physical activity B) sleep quality, C) sleep duration. The colours within each of the proportion categories correspond with inclusion in patterns of change categories. Omitted proportion labels in Figure 1C are, more-than-recommended sleep duration in 2011 and less-than-recommended sleep duration in 2013, 0.19%; less-than-recommended sleep duration in 2011 and more-than-recommended sleep duration in 2013, 0.16%; more-than-recommended sleep duration in 2011 and more-than-recommended sleep duration in 2013, 2.55%; recommended sleep duration in 2011 and more-than-recommended sleep duration in 2013, 2.55%.

Table 1. Sociodemographic and health characteristics of participants in 2011 (n= 3,649)

	N (%)
Age (years)	
42-54	1,528 (41.87)
55-64	1,566 (42.92)
65-70	555 (15.21)
Gender, male %	1,575 (43.16)
Education,	
School-only	1,291 (35.38)
Diploma /Vocational	1,051 (28.80)
Bachelor degree or higher	1,307 (35.82)
Hours of Work/week	
Not in the workforce	420 (11.55)
Retired	765 (21.05)
0-35.0 hours/week	850 (23.38)
35.1- 40 hours/week	806 (22.17)
>40 hours/week	794 (21.84)
BMI (kg/m²)	
<25	1,418 (38.86)
25-30	1,393 (38.17)
>30	838 (22.97)
No. of chronic health conditions	
0 chronic conditions	1,127 (30.89)
1-2 chronic conditions	1,687 (46.23)
≥3 chronic conditions	835 (22.88)
Psychological Distress (Kessler 6)	
No distress (0-7)	476 (86.96)
Distress (8-24)	3,173 (13.04)

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Table 2. Behavioural characteristics in 2011 and 2013, and behavioural change patterns 2011-2013, of participants (n = 3,649).*

Behavioural characteristics 2011	N (%)
Physical activity (minutes/week)	
Insufficiently active (<150)	1,434 (39.30)
Meeting activity recommendations (150-300)	820 (22.47)
Highly active (>300)	1,395 (38.23)
Sleep Quality	
Poor	1,381 (37.85)
Good	1,389 (38.07)
Excellent	879 (24.09)
Sleep duration	
Less-than-recommended	865 (23.71)
Recommended	2,601 (71.28)
More-than-recommended	183 (5.02)
Behavioural characteristics 2013	
Physical activity (minutes/week)	
Insufficiently active (<150)	1,367 (37.46)
Meeting activity recommendations (150-300)	828 (22.69)
Highly active (>300)	1,454 (39.85)
Sleep Quality	
Poor	1,340 (36.72)
Good	1,395 (38.28)
Excellent	914 (25.05)
Sleep duration	
Less-than-recommended	858 (23.51)
Recommended	2,599 (71.22)
More-than-recommended	192 (5.26)
Behavioural Change Patterns	
Physical activity patterns 2011-2013	
Remained inactive	906 (24.83)
Decreased	721 (19.76)
Increased	803 (22.01)
Remained active	1,219 (33.41)
Sleep quality patterns 2011-2013	
Remained poor	917 (25.13)
Decreased	682 (18.69)
Increased	768 (21.05)
Remained good	1,282 (35.13)
Sleep duration patterns 2011-2013	
Remained sub-optimal	667 (18.28)
Became sub-optimal	383 (10.50)
Became optimal	381 (10.44)
Remained optimal	2,218 (60.78)

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Table 3. Association between patterns of change in sleep quality and sleep duration with patterns of change physical activity between 2011 and 2013.*

Remained inactive 2011-2013 - base outcome	Increased physical activity 2011-2013		Decreased physical activity 2011-2013		Remained active 2011-2013	
	RR (95% CI)	p	RR (95% CI)	p	RR (95% CI)	p
Change in sleep quality 2011-2013						
Remained poor	Ref 1.03		Ref 1.39		Ref 1.07	
Decreased	(0.77-1.39)	0.839	(1.03-1.86)	0.032	(0.81-1.41)	0.649
Increased	1.30 (0.98 -1.72)	0.071	1.11 (0.82-1.50)	0.488	1.38 (1.06-1.80)	0.018
Remained good	1.05 (0.80-1.36)	0.736	1.14 (0.87-1.49)	0.355	1.42 (1.12-1.81)	0.004
Change in sleep duration 2011-2013						
Remained sub-optimal	Ref 0.94		Ref 1.04		Ref 1.02	
Became sub-optimal	(0.64-1.37)	0.747	(0.72-1.50)	0.821	(0.73-1.44)	0.890
Became optimal	1.41 (0.98-2.04)	0.067	1.09 (0.75-1.60)	0.654	1.17 (0.83-1.65)	0.373
Remained optimal	1.25 (0.96-1.63)	0.099	0.99 (0.76-1.30)	0.962	1.18 (0.93-1.50)	0.183

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Table 4. Association between patterns of change in physical activity and sleep duration with patterns of change in sleep quality between 2011 and 2013.*

Remained poor sleep quality 2011-2013 - base outcome	Increased sleep quality 2011-2013		Decreased sleep quality 2011-2013		Remained good sleep quality 2011-2013	
	RR (95% CI)	p	RR (95% CI)	p	RR (95% CI)	p
Change in physical activity 2011-2013						
Remained inactive	Ref 1.12		Ref 1.39		Ref 1.13	
Decreased	(0.83-1.51)	0.477	(1.04-1.88)	0.028	(0.86-1.49)	0.365
Increased	1.30 (0.98-1.72)	0.073	1.03 (0.77-1.39)	0.836	1.05 (0.80-1.36)	0.740
Remained active	1.38 (1.06-1.80)	0.018	1.07 (0.81-1.42)	0.624	1.42 (1.12-1.81)	0.004
Change in sleep duration 2011-2013						
Remained sub-optimal	Ref 1.38		Ref 2.23		Ref 2.09	
Became sub-optimal	(0.95-2.02)	0.093	(1.55-3.21)	<0.001	(1.49-2.93)	<0.001
Became optimal	2.23 (1.56-3.17)	<0.001	1.43 (0.95-2.16)	0.088	2.58 (1.84-3.61)	<0.001
Remained optimal	3.01 (2.33-3.89)	<0.001	3.13 (2.38-4.10)	<0.001	4.52 (3.55-5.76)	<0.001

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Table 5. Association between patterns of change in physical activity and sleep quality with patterns of change in sleep duration between 2011 and 2013.*

Remained sub-optimal sleep duration 2011-2013 - base outcome	Became optimal sleep duration 2011-2013		Became suboptimal sleep duration 2011-2013		Remained optimal sleep duration 2011-2013	
	RR (95% CI)	p	RR (95% CI)	p	RR (95% CI)	p
Change in physical activity 2011-2013						
Remained inactive	Ref 1.09		Ref 1.05		Ref 1.00	
Decreased	(0.74-1.59) 1.41	0.659	(0.73-1.51) 0.94	0.811	(0.76-1.30) 1.25	0.974
Increased	(0.98-2.04) 1.18	0.065	(0.65-1.38) 1.03	0.760	(0.96-1.63) 1.18	0.097
Remained active	(0.84-1.67) 1.18	0.347	(0.73-1.44) 1.03	0.870	(0.93-1.51) 1.18	0.176
Change in sleep quality 2011-2013						
Remained poor	Ref 1.43		Ref 2.23		Ref 3.13	
Decreased	(0.95-2.15) 2.21	0.091	(1.55-3.21) 1.38	<0.001	(2.39-4.10) 3.01	<0.001
Increased	(1.55-3.15) 2.57	<0.001	(0.95-2.02) 2.08	0.092	(2.33-3.89) 4.51	<0.001
Remained good	(1.83-3.60) 2.57	<0.001	(1.48-2.91) 2.08	<0.001	(3.54-5.74) 4.51	<0.001

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