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Understanding 24-hour movement behaviours and their associations with children's psychosocial health during the transition from primary to secondary school

Kar Hau Chong

UNIVERSITY OF WOLLONGONG AUSTRALIA

Understanding 24-hour movement behaviours and their associations with children's psychosocial health during the transition from primary to secondary school

A thesis submitted in fulfilment of the requirements for the award of the degree:

Doctor of Philosophy

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by

Kar Hau Chong

BSc. Nutrition Science (Hon.)
MSc. Health Science (Nutrition)

Supervisors:
Prof. Anthony D. Okely,
Assoc. Prof. Anne-Maree Parrish and Assoc. Prof. Dylan P. Cliff

School of Health and Society

Faculty of the Arts, Social Sciences and Humanities

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Abstract

Background

The transition from primary to secondary school is one of the life transition periods during which significant behavioural changes may occur. However, there is little evidence on concurrent changes in sleep, sedentary behaviour and physical activity (PA) (collectively known as 24-hour movement behaviours) over a 24-hour period during this school transition period. Further, the combined associations between time spent in 24-hour movement behaviours and psychosocial health are still under-researched in children. This information may inform the development of future movement behaviour intervention strategies and guidelines to assist children in making a healthy transition to secondary school. The overall aim of this doctoral thesis was to explore changes in 24-hour movement behaviours and their associations with children's psychosocial health over the transition from primary to secondary school.

Methods

This thesis is comprised of four research papers, one of which is a systematic literature review and the other three are original research studies using data from two longitudinal surveys. The first and third studies analysed primary data from a longitudinal school-based survey that followed a cohort of children in New South Wales, Australia from their final year of primary school (Year-6; aged 10-12y) to their first year of secondary school (Year-7; aged 11-13y). The second study used national data from Waves 4 (2010) and 5 (2012) of the Longitudinal Study of Australia Children (Kindergarten cohort) when participants were in primary (aged 10-11y) and secondary school (aged 12-13y), respectively.

Results

The systematic literature review identified five articles that reported only changes in PA, while one reported changes in both PA and sedentary behaviour during the school transition period. There were no studies that examined changes in sleep duration or changes in all three movement

behaviours concurrently.

The first study (n=83) investigated changes in the accelerometer-measured 24-hour movement behaviour composition and adherence to the Australian 24-Hour Movement Guidelines during the school transition period. An unfavourable change was observed in the movement behaviour composition, with increased time spent sedentary and decreased time in sleep and PA. The change in the weekday movement behaviour composition was significantly more prominent compared to that of the weekend. Furthermore, there was a substantial decrease in the proportion of children meeting the integrated 24-hour movement guidelines (i.e., from 20.5% to 3.6%).

The second study (n=909) investigated changes in the domain-specific movement behaviour composition as measured by a single-day time-use diary (67.4% school day; 32.6% non-school day), and explored whether these changes were associated with changes in children's psychosocial health during this transition period. A more drastic change in movement behaviour composition was observed among the school day sample compared to the non-school day sample. Furthermore, the change in movement behaviour composition was significantly related to changes in prosocial behaviour among boys. Specifically, increased time spent in social activities and recreational screen use (relative to other activity domains) were associated with decreased prosocial behaviour. There were no significant associations between the change in movement behaviour composition and the changes in psychosocial health among girls.

The third study examined the cross-sectional (n=127) and longitudinal associations (n=88) between 24-hour movement behaviour composition, recreational screen use and children's psychosocial health. The movement behaviour composition and recreational screen use levels were independently associated with psychosocial health outcomes cross-sectionally but not longitudinally. Relative to other behaviours, more time spent in sleep and less time spent in light-intensity PA were associated with lower levels of internalising problems and total

psychosocial difficulties. Conversely, higher sedentary time was associated with greater internalising problems. High levels of recreational screen use (>2 h/day) were associated with greater externalising problems, total psychosocial difficulties and psychological distress.

Conclusion

This thesis has provided new evidence to advance the understanding of children's 24-hour movement behaviours and their combined associations with psychosocial health during the transition from primary to secondary school. It is recommended that an integrated intervention approach addressing the full composition of 24-hour movement behaviours be adopted to effectively improve children's movement behaviour profiles during this transition period. Future research should also continue to measure and analyse both intensity- and domain-specific movement behaviour compositions given the differing associations noted with children's psychosocial health.

Acknowledgements

It has been a long journey (March 2017-January 2022) to complete this PhD thesis, and I would not have been able to do it without the continued support and guidance of my supervisors – Prof. Anthony Okely, Assoc. Prof. Anne-Maree Parrish and Assoc. Prof. Dylan Cliff. Tony, I am so appreciative of your trust and confidence in me as well as the opportunities you have provided me with to work on various research projects that have contributed significantly to my personal and professional development. Anne-Maree, thank you for always being there for me, not just as a supervisor but also as someone whom I can talk to during difficult times. Dylan, thank you for always pointing me in the right direction and providing me with detailed and constructive feedback on how to further improve the quality of my work.

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Certification

*I, **Kar Hau Chong**, declare that this thesis submitted in fulfilment of the requirements for the conferral of the degree **Doctor of Philosophy**, from the University of Wollongong, is wholly my own work unless otherwise referenced or acknowledged. This document has not been submitted for qualifications at any other academic institution.*

Kar Hau Chong
13th April 2022

List of abbreviations

ASAQ:	Adolescent Sedentary Activity Questionnaire
BAZ:	Body Mass Index Z-scores
CoDA:	Compositional Data Analysis
H:	Number of Hours
ILRS:	Isometric Log-Ratios
IRSD:	Index of Relative Socio-Economic Disadvantage
K-10:	Kessler's Psychological Distress Scale (10 Items)
LPA:	Light-Intensity Physical Activity
LSAC:	Longitudinal Study of Australian Children
M:	Mean
MIN:	Number of Minutes
MPA:	Moderate-Intensity Physical Activity
MVPA:	Moderate- to Vigorous-Intensity Physical Activity
N:	Number (of participants, studies, etc.)
SD:	Standard Deviation
SDQ:	Strengths and Difficulties Questionnaire
SED:	Sedentary Time
SEIFA:	Socio-Economic Indexes for Areas
SES:	Socio-Economic Status
SPSS:	Statistical Package for the Social Sciences
ST:	Screen Time
VPA:	Vigorous-Intensity Physical Activity
Y:	Years (of age)

Statement of thesis style

In agreement with my PhD supervisors, this thesis has been prepared in accordance with a journal article compilation style using the UOW Harvard referencing style. The journal article compilation style allowed the research findings to be disseminated broadly in a timely manner to facilitate the development of research fields.

The findings of this PhD thesis have been reported in four individual manuscripts that have been published in peer-reviewed journals (Chapters 3, 5, 6 and 7). These include a systematic literature review (Chapter 3) and three original research studies (Chapters 5 to 7). The manuscripts have been presented as individual chapters in this thesis, with linking text added to establish connections between them. Other sections of this thesis include a general introductory chapter, an overall literature review chapter, a methodology chapter and a general discussion chapter.

The impact of COVID-19 pandemic on research project:

Due to the COVID-19-related restrictions on research activities (i.e., activities involving face-to-face interactions should be suspended) and considering the candidature time limits, a decision was made in April 2020 to terminate the data collection activities for the longitudinal research project conducted as part of this thesis (Survey 1; see Chapter 4 for more details). This resulted in the loss of 22% of follow-up data (30 participants) for use in the two original research studies reported in Chapters 5 and 7.

List of publications from the thesis

Manuscript 1 (Chapter 3)

Chong, KH, Parrish, A-M, Cliff, DP, Kemp, BJ, Zhang, Z & Okely, AD 2020, 'Changes in physical activity, sedentary behaviour and sleep across the transition from primary to secondary school: a systematic review', *J Sci Med Sport*, vol. 23, no. 6, pp. 498-505, doi: https://doi.org/10.1016/j.jsams.2019.12.002. (Journal metrics: 17/88 in the Sport Sciences category, impact factor ─ 4.319; Number of citations: 19)

Manuscript 2 (Chapter 5)

Chong, KH, Parrish, A-M, Cliff, DP, Dumuid, D & Okely, AD 2021, 'Changes in 24-hour movement behaviours during the transition from primary to secondary school among Australian children', *Eur J Sport Sci*, doi: https://doi.org/10.1080/17461391.2021.1903562. (Journal metrics: 21/88 in the Sport Sciences category, impact factor ─ 4.050; Number of citations: 7)

Manuscript 3 (Chapter 6)

Chong, KH, Dumuid, D, Cliff, DP, Parrish, A-M, & Okely, AD 2021, 'Changes in 24-hour domain-specific movement behaviours and their associations with children's psychosocial health during the transition from primary to secondary school: a compositional data analysis approach'. *J Phys Act Health*, doi: https://doi.org/10.1123/jpah.2021-0630. (Journal metrics: 79/176 in the Public, Environmental & Occupational Health category; Impact factor: 2.592)

Manuscript 4 (Chapter 7)

Chong, KH, Parrish, A-M, Cliff, DP, Dumuid, D & Okely, AD 2021, 'Cross-sectional and longitudinal associations between 24-hour movement behaviours, recreational screen use and psychosocial health outcomes in children: A compositional data analysis approach', *Int J Environ Res Public Health*, vol. 18, p. 5995, doi: https://doi.org/10.3390/ijerph18115995.

(Journal metrics: 42/176 in the Public, Environmental & Occupational Health category, impact factor ─ 3.390; Number of citations: 3)

Note. The journal metrics were obtained from the Journal Citation Report 2021 published by Clarivate Analtyics (https://jcr.clarivate.com/jcr/home). The citation information was obtained from the Google Scholar page (https://scholar.google.com/; as of 13th April 2022)

Authors' contributions to publications

Manuscript 1 (Chapter 3)

Kar Hau Chong conceived and designed the study, conducted the search on academic databases, reviewed the literature, conducted the risk of bias assessment, synthesised the results from literature, and drafted the initial manuscript. Zhiguang Zhang conducted the search on academic databases and reviewed the literature. Byron J. Kemp reviewed the literature and conducted the risk of bias assessment. Anne-Maree Parrish, Dylan P. Cliff and Anthony D. Okely conceived and designed the study, and provided advice on the risk of bias assessment and synthesis of results. All authors reviewed and approved the final manuscript.

Manuscript 2 (Chapter 5)

Kar Hau Chong conceived and designed the study, conducted the data collection, curated and analysed the data, interpreted the findings, and drafted the initial manuscript. Anne-Maree Parrish conceived and designed the study, secured the funding, and provided advice on data analysis and interpretation of findings. Dylan P. Cliff and Anthony D. Okely conceived and designed the study, and provided advice on data analysis and interpretation of findings. Dorothea Dumuid provided guidance on data analysis and interpretation of findings. All authors reviewed and approved the final manuscript.

Manuscript 3 (Chapter 6)

Kar Hau Chong conceived and designed the study, gained access to LSAC dataset, curated and analysed the data, interpreted the findings, and drafted the initial manuscript. Dorothea Dumuid provided support on data curation and analysis, and interpretation of findings. Dylan P. Cliff, Anne-Maree Parrish and Anthony D. Okely conceived and designed the study, and provided advice on data analysis and interpretation of findings. All authors reviewed and approved the final manuscript.

Manuscript 4 (Chapter 7)

Kar Hau Chong conceived and designed the study, conducted the data collection, curated and analysed the data, interpreted the findings, and drafted the initial manuscript. Anne-Maree Parrish conceived and designed the study, secured the funding, and provided advice on data analysis and interpretation of findings. Dylan P. Cliff and Anthony D. Okely conceived and designed the study, and provided advice on data analysis and interpretation of findings. Dorothea Dumuid provided guidance on data analysis and interpretation of findings. All authors reviewed and approved the final manuscript.

All authors hereby agree with the authors' contributions statement:

Kar Hau Chong 15th November 2021	**Prof. Anthony D. Okely** 27th January 2022
Assoc. Prof. Anne-Maree Parrish 21st January 2022	**Assoc. Prof. Dylan P. Cliff** 20th January 2022
Dr. Dorothea Dumuid 16th November 2021	**Dr. Byron J. Kemp** 15th November 2021
Dr. Zhiguang Zhang 15th November 2021	

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Chapter 1: Introduction and aim

1.1 Introduction

From a movement perspective, a 24-hour day is comprised of periods of sleep, sedentary behaviour and physical activity (Pedišić 2014). These health-related behaviours are collectively known as 24-hour movement behaviours because they reflect the full range of the movement intensity continuum (i.e., from no/low to high movement) over the course of a day (Tremblay et al. 2016; Chaput et al. 2014). A compelling body of evidence indicates that time spent in these movement behaviours are individually associated with health and developmental outcomes in children and adolescents (Carson et al. 2016; Chaput et al. 2016; Poitras et al. 2016). Until recently, most epidemiological studies have considered each individual movement behaviour as a separate and independent entity, ignoring the fact that the times spent in these three movement behaviours are exhaustive components of a 24-hour day (Chastin et al. 2015; Pedišić 2014). This means that the total time of all behaviours combined is always capped at 24 hours per day. Therefore, time spent in one behaviour necessarily displaces time spent in at least one of the remaining behaviours, which further indicates that these movement behaviours and their associations with health outcomes should be studied relative to each other rather than in isolation (Pedišić, Dumuid & Olds 2017; Chastin et al. 2015). This realisation has prompted a paradigm shift away from considering each movement behaviour in isolation towards examining the combinations of movement behaviours over the course of a day using an integrated approach (Rosenberger et al. 2019; Pedišić, Dumuid & Olds 2017; Tremblay et al. 2016; Chastin et al. 2015; Chaput et al. 2014).

In accordance with the new integrated movement behaviour paradigm, several countries (e.g., Canada, New Zealand and Australia) have developed and released national 24-hour integrated movement guidelines for school-aged children and adolescents (Australian Government Department of Health 2019; New Zealand Ministry of Health 2017; Tremblay et al. 2016).

These guidelines provide evidence-informed recommendations for a 'healthy' 24-hour day in relation to health and development outcomes, comprising a combination of high levels of physical activity (e.g., at least 60 min of moderate- to vigorous-intensity physical activity (MVPA)), low levels of sedentary behaviour (including 2 h or less of sedentary recreational screen time) and sufficient sleep (i.e., 9-11 h for ages 5-13y and 8-10 h for ages 14-17y) (Australian Government Department of Health 2019). A recent review of studies examining adherence to the 24-hour movement guidelines revealed that only a small proportion of children (4.8%-10.8%) and adolescents (1.6%-9.7%) met all three individual movement behaviour recommendations (Rollo, Antsygina & Tremblay 2020), despite emerging evidence on their associated health benefits (e.g., lower adiposity, better mental health) (Rollo, Antsygina & Tremblay 2020; Sampasa-Kanyinga et al. 2020). Considering the possibility that movement behaviours established during childhood and adolescence may track into adulthood (Hysing et al. 2020; Hayes et al. 2019), and that many of the chronic health conditions that are associated with movement behaviours have their genesis in childhood (Halfon, Verhoef & Kuo 2012), it is important to understand how 24-hour movement behaviours develop and change over time and to identify the key periods and settings for interventions.

The transition from primary (ages ~5-12y) to secondary school (ages ~12-17y) is a life transition where significant behavioural changes occur (Gropper et al. 2020). For most children, this transition period is accompanied by significant environmental changes (physical, social and/or academic) (McGaughey et al. 2020; Morton et al. 2016; Hanewald 2013), which often co-occur with puberty-associated developmental changes (e.g., biological and emotional) (Patton & Viner 2007) that may interact to influence their movement behaviours. Evidence from recent systematic reviews indicates that children spend more time engaging in sedentary behaviour (Pearson et al. 2017) and less time in physical activity (Chong et al. 2020 – see Chapter 3) as they make the transition from primary to secondary school. However, it is important to note that most of the published literature has focused on changes in one specific

movement behaviour (i.e., physical activity or sedentary behaviour); it is unknown how time spent in the combination of these 24-hour movement behaviours, referred to as their composition, may change over the school transition period (Chong et al. 2020). Because 24-hour movement behaviours are intrinsically co-dependent (Chastin et al. 2015; Pedišić 2014) and the reallocations of time between these behaviours could have unique influences on health and wellbeing (Gilchrist et al. 2021; García-Hermoso et al. 2018; Grgic et al. 2018), a more detailed investigation using an integrated approach is warranted to better understand the changes in children's 24-hour movement behaviour composition during this transition period.

It has been demonstrated that the combinations or compositions of 24-hour movement behaviours may have important health implications for children and adolescents (Rollo, Antsygina & Tremblay 2020; Saunders et al. 2016). Initial evidence suggests that more sleep, less sedentary time, less light-intensity physical activity (LPA) and/or greater MVPA (relative to other behaviours) are favourably associated with multiple health outcomes (e.g., adiposity, fitness, cardiometabolic biomarkers) in children and adolescents (Rollo, Antsygina & Tremblay 2020), although the 'optimal' composition may vary between health outcomes (Dumuid et al. 2021). However, there is a lack of evidence regarding the contribution of 24-hour movement behaviours to children's health and wellbeing outcomes during the transition from primary to secondary school. Of particular interest is the psychosocial health aspects (i.e., mental health and social health), which also changes significantly over the school transition period (Evans, Borriello & Field 2018).

Indeed, the association between 24-hour movement behaviours and psychosocial health is under-researched among children and adolescents (Rollo, Antsygina & Tremblay 2020; Sampasa-Kanyinga et al. 2020; Saunders et al. 2016). There is some evidence that meeting all three individual movement behaviour recommendations within the 24-hour integrated movement guidelines is associated with better mental health outcomes in children and

adolescents, with a dose-response gradient shown between the number of recommendations met and more favourable mental health outcomes (Sampasa-Kanyinga et al. 2020). Nevertheless, there is limited research exploring the combined associations between 24-hour movement behaviours and psychosocial health outcomes using a compositional data analysis (CoDA) approach, which allows for the full 24-hour movement behaviour time-use composition to be considered (Fairclough et al. 2021; Sampasa-Kanyinga et al. 2020). Unlike traditional statistical approaches, CoDA considers the compositional properties and co-dependent nature of movement behaviour data, allowing their associations with health outcomes to be analysed relative to each other while being adjusted for the full movement behaviour composition (Dumuid et al. 2018; Chastin et al. 2015). To strengthen the evidence on this topic, it has been recommended that future research include the use of longitudinal designs, robust measures of movement behaviours, validated items for psychosocial health indicators, and the CoDA approach (Sampasa-Kanyinga et al. 2020).

Another important aspect to consider when interpreting the health implications of movement behaviours is the type and context of the behaviours. This is particularly relevant for the sedentary behaviour component, where screen-based sedentary activities have been identified as the most concerning subset of sedentary behaviour due to their negative associations with health and development outcomes in children and adolescents (LeBlanc et al. 2017). There is consistent evidence that excessive screen time is associated with poorer psychosocial health outcomes (e.g., depressive symptoms, psychological distress) among children and adolescents (Oswald et al. 2020; Sanders et al. 2019; Stiglic & Viner 2019; Liu, Wu & Yao 2016). However, it remains largely unknown whether the effects of screen time are explained by the content and context of the screen viewing or the displacement of opportunities for other health-promoting activities (e.g., physical activity) (Oswald et al. 2020; Stiglic & Viner 2019). There is also a lack of evidence examining if either total sedentary time (i.e., time spent in all sedentary activities) or specific types of sedentary behaviour are more strongly related to psychosocial health

(Fairclough et al. 2021). As recreational screen use is also likely to affect the time spent in 24-hour movement behaviours (e.g., higher sedentary time and shorter sleep duration) (Harrington et al. 2021; Twenge, Hisler & Krizan 2019), it is important to determine whether the association between recreational screen use and psychosocial health is independent of children's 24-hour movement behaviour composition, and vice versa.

1.2 Aim and research questions

The overall aim of this doctoral thesis was to explore changes in 24-hour movement behaviours and their associations with children's psychosocial health during the transition from primary to secondary school. To address this over-arching aim, the following research questions were investigated:

Research Question 1:

How does the distribution of time spent in different intensities and domains of 24-hour movement behaviours change across the transition from primary to secondary school?

Sub-research questions:

1.1 Does the change in 24-hour movement behaviour composition differ by day type (weekdays and weekends)?

1.2 Is the change in 24-hour movement behaviour composition moderated by the child's socio-demographic (sex, socio-economic status) and health characteristics (body weight status and pubertal development)?

1.3 Is the change in 24-hour movement behaviour composition moderated by a change in the school environment (i.e., transitioning to a new secondary school)?

1.4 How does adherence to the Australian 24-Hour Movement Guidelines for Children and Young People (aged 5-17y) change during the school transition period?

Research Question 2:

Are 24-hour movement behaviours associated with children's psychosocial health during the transition from primary to secondary school?

Sub-research questions:

2.1 Is the change in 24-hour movement behaviour composition associated with changes in children's psychosocial health during the school transition period?

2.2 Are the 24-hour movement behaviour composition and recreational screen use independently associated with children's psychosocial health, both cross-sectionally and longitudinally?

1.3 Significance

Life transitions have been conceptualised as natural interventions that are often associated with significant behavioural changes across the life course (Gropper et al. 2020). The transition from primary to secondary school is of particular interest in this thesis because it is considered as one of the most stressful events in a child's life, with substantial changes occurring at both the individual (e.g., psychological wellbeing) and environment levels (e.g., social, academic) that could potentially have long-term influences on their health and wellbeing (Evans, Borriello & Field 2018; West, Sweeting & Young 2010). Thus, a greater understanding of children's movement behaviour patterns during the school transition is warranted to inform the development of intervention strategies to support children in making a healthy transition to secondary school. Currently, there is a lack of studies assessing concurrent changes in time allocations between sleep, sedentary behaviour and physical activity, which are co-dependent behaviours that constitute the full 24-hour day (Chong et al. 2020). This information may help to guide the selection of more promising intervention approaches by identifying the behavioural components that are most in need of targeting during this school transition period.

While each individual movement behaviour has been shown to be associated with children's psychosocial health (Carson et al. 2016; Chaput et al. 2016; Poitras et al. 2016), there remains a lack of evidence regarding the contributions of these movement behaviours to psychosocial health during the school transition period. Further, it is unclear whether the health associations of 24-hour movement behaviours are independent of children's recreational screen use levels, and vice versa. This information may contribute a more detailed understanding of the impact of different combinations of movement behaviours on psychosocial health among children – an area that is currently under researched (Rollo, Antsygina & Tremblay 2020; Sampasa-Kanyinga et al. 2020). Specifically, it adds to the body of knowledge on the combined (i.e., the overall movement behaviour composition) and relative associations (e.g., sleep relative to physical activity-sedentary behaviour) of 24-hour movement behaviours with children's health; and justifies if recreational screen use should be viewed as a distinct time-use behaviour in relation to psychosocial health outcomes.

1.4 Delimitations

This thesis utilised data from two surveys: a one-year longitudinal school-based survey (Survey 1; Chapters 5 and 7) and the Longitudinal Study of Australian Children (LSAC) (Sanson et al. 2002) (Survey 2; Chapter 6).

Survey 1 was delimited in the following ways:

i. Participants were healthy children followed from their final year of primary school (Year 6; ages 10-12y) to the first year of secondary school (Year-7; ages 11-13y) (April 2018-March 2020).
ii. Participating schools were located within a 400 km radius of the city of Wollongong in New South Wales, Australia.
iii. Time spent in 24-hour movement behaviours was measured for six consecutive days (24 h/day) using a wrist-worn accelerometer (GENEActiv).

iv. Participation in specific types of sedentary behaviour (including recreational screen use) (Hardy et al. 2016) and physical activity (Eime et al. 2016) were assessed using self-report measures that were adapted from previous research.

v. Psychosocial health was assessed using the self-report version of the Strengths and Difficulties Questionnaire (SDQ) (Goodman 1997) and the Kessler's Psychological Distress Scale (K-10) (Kessler et al. 2002).

Survey 2 was delimited in the following ways:

i. Participants were children living in Australia who participated in the LSAC study (Kindergarten cohort) and were in their last two years of primary school at Wave 4 (2010; ages 10-11y) and first two years of secondary school at Wave 5 (2012; ages 12-13y).

ii. Time spent in domain-specific movement behaviours was assessed using a single day time-use diary (Corey et al. 2014).

iii. Psychosocial health was assessed using the self-report version of the Strengths and Difficulties Questionnaire (SDQ) (Goodman 1997).

1.5 Overview of thesis

This thesis by compilation consists of four manuscripts, one of which is a systematic literature review (Chapter 3) and the other three are original research studies (Chapters 5 to 7). Each manuscript is presented as an individual chapter in this thesis. Table 1.1 summarises the content of the study chapters included in this thesis.

Table 1.1 Outline of the thesis

Chapter	Description of the thesis chapter
2	**Theoretical framework and literature review:** This chapter provides an overview of the theoretical framework and literature related to this thesis. It also highlights the research gaps that formed the aims and research questions of this thesis.
3	**Manuscript 1: Changes in physical activity, sedentary behaviour and sleep across the transition from primary to secondary school: a systematic review** (Chong et al. 2020) This chapter addresses Research Question 1 by systematically reviewing previous studies that reported changes in time spent in physical activity, sedentary behaviour and sleep across the transition from primary to secondary school.
4	**Methodology:** This chapter provides an overview of the data sources and statistical analyses used in the three original research studies as described in the following chapters.
5	**Manuscript 2 (Study 1): Changes in 24-hour movement behaviours during the transition from primary to secondary school among Australian children** (Chong et al. 2021a) This chapter addresses Research Questions 1 by examining changes in the accelerometer-measured 24-hour movement behaviour composition and self-report measures of sedentary behaviour and physical activity, and the resulting changes in adherence to the Australian 24-Hour Movement Guidelines during the transition from primary to secondary school.
6	**Manuscript 3 (Study 2): Changes in 24-hour domain-specific movement behaviours and their associations with children's psychosocial health during the transition from primary to secondary school: a compositional data analysis** (Chong et al. 2022) This chapter addresses Research Question 1 by examining changes in the 24-hour domain-specific movement behaviour composition during the transition from primary to secondary school. This chapter also addresses Research Question 2 by exploring whether the change in 24-hour movement behaviour composition is associated with changes in psychosocial health during this school transition period.
7	**Manuscript 4 (Study 3): Cross-sectional and longitudinal associations between 24-hour movement behaviours, recreational screen use and psychosocial health outcomes in children: a compositional data analysis approach** (Chong et al. 2021b) This chapter addresses Research Question 2 by examining the cross-sectional and longitudinal associations between the 24-hour movement behaviour composition, recreational screen use and psychosocial health in children.
8	**General Discussion:** This concluding chapter summarises the main findings of this thesis and discusses them in the context of the broader evidence base. It also discusses the implications of the study findings, the overall strengths and limitations of the thesis, and provides recommendations for future research.

1.6 Definition of key terms

- **24-hour movement behaviours** is an umbrella term that encapsulates physical behaviours occurring on a movement intensity continuum across a 24-hour period (Tremblay et al. 2016; Chaput et al. 2014). In this thesis, 24-hour movement behaviours are broadly classified into sleep, sedentary behaviour and physical activity.
- **Sleep** is defined as a naturally recurring state of body and mind characterised by altered consciousness, relatively inhibited sensory activity, inhibition of nearly all voluntary muscles and reduced interactions with surroundings (Chaput, Saunders & Carson 2017).
- **Sedentary behaviour** refers to any waking behaviour characterised by low energy expenditure (i.e., ≤1.5 metabolic equivalents) that performed in a sitting, reclining or lying posture (Tremblay et al. 2017).
- **Physical activity** refers to any bodily movement produced by skeletal muscles that requires energy expenditure above the basal level (Caspersen, Powell & Christenson 1985).
- **Screen time** refers to the time spent on screen-based behaviours, which can be performed while being sedentary or physically active (Tremblay et al. 2017).
- **Recreational screen use** refers to non-school-related screen-based behaviours (Tremblay et al. 2017).
- **Psychosocial health** is an umbrella term that encompasses mental and social dimensions of health (World Health Organization 1948).
- **School transition** is described as a process of moving from one education system to another. In this thesis, it refers to the transition from primary to secondary education systems.
- **Primary education** comprises a foundation grade followed by Years 1 to 6 (or 7) in the Australian education context (Australian Curriculum, Assessment and Reporting Authority 2021).

- **Secondary education** consists of the first year of secondary school (Year 6 or 7) to Year 12 in the Australian education context (Australian Curriculum, Assessment and Reporting Authority 2021).
- **Compositional data** are made up of mutually exclusive parts of a finite whole (e.g., 24 h) and provide only relative information (Aitchison 1982).
- **Compositional data analysis** is a branch of statistics that deals with the analysis of compositional data (Aitchison 1982).

1.7 References

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Chapter 2: Theoretical framework and literature review

Chapter 1 provided the background and rationale for the research undertaken as part of this thesis. A broad overview of the thesis structure, including the aims and research questions, was also presented. This chapter introduces the theoretical framework and provides a review of literature related to the thesis. The first section of this chapter explains the key concepts of the theoretical framework and its connection with the research questions. The subsequent section provides the definitions and prevalence data on 24-hour movement behaviours and psychosocial health in children and adolescents (Sections 2.2 and 2.3). This is followed by a review of literature on the transition from primary to secondary school and its association with 24-hour movement behaviours and psychosocial health (Sections 2.4 to 2.6), and the associations between 24-hour movement behaviours and psychosocial health (Section 2.7). The final section outlines the key knowledge gaps in the evidence base that need to be addressed.

2.1 Theoretical framework

This thesis draws on the theoretical concepts from the Framework for Viable Integrative Research in Time-Use Epidemiology (VIRTUE) (Pedišić, Dumuid & Olds 2017). The VIRTUE framework was developed to guide time-use research, with a specific focus on health-related time-use behaviours (e.g., sleep, sedentary behaviour and physical activity) occurring over a 24-hour day. This theoretical framework conceptualises time-use behaviours as a type of compositional data (i.e., their total sum always constitutes a finite period of time), whereby their relationships to health, determinants and correlates should be analysed and interpreted using a statistical technique that accounts for the compositional properties of time-use data (e.g., the compositional data analysis method (CoDA)) (Pedišić, Dumuid & Olds 2017). The framework was developed by incorporating key elements of three established models: the social-ecological model (Sallis et al. 2006; Stokols 1996; 1992), the Behavioural Epidemiology Framework (Sallis, Owen & Fotheringham 2000), and the Activity Balance Model (Pedišić 2014). Specifically, the framework identifies five research areas that should be addressed to gain a

thorough understanding of the prevalence, causes, and consequences of time-use behaviours; and to inform interventions aimed at promoting healthy time-use behaviours across different populations (Pedišić, Dumuid & Olds 2017) (see Figure 2.1). These include: 1) methodological research in time-use epidemiology; 2) outcomes of health-related time-use compositions; 3) optimal balance, prevalence, and trends of time-use compositions; 4) determinants of optimal time-use; and 5) time-use interventions (Pedišić, Dumuid & Olds 2017). To date, the VIRTUE framework has been applied to time-use studies addressing Research Areas 1, 2, 3 and/or 4 among children (Kuzik 2020; St. Laurent et al. 2020) and adult populations (Liangruenrom 2020; Gupta et al. 2018).

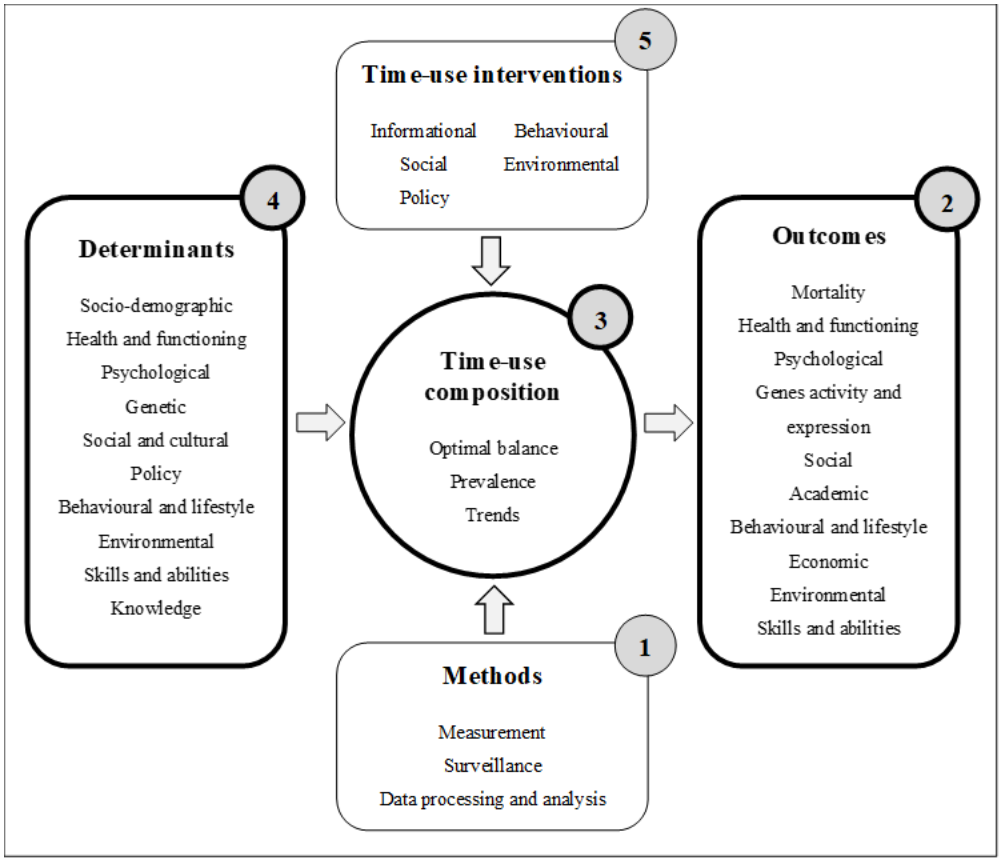

Figure 2.1 The Framework for Viable Integrative Research in Time-Use Epidemiology (VIRTUE framework) (Pedišić, Dumuid & Olds 2017)

Note. The bolded boxes indicate the research areas to be addressed in this thesis.

This thesis focuses on addressing the main research topics outlined in Research Areas 2, 3 and 4 within the VIRTUE framework (Table 2.1) : 1) the associations between time spent in 24-hour movement behaviours and children's psychosocial health (Research Area 2; Chapters 6 and 7); 2) the longitudinal changes in 24-hour movement behaviours (Research Area 3; Chapters 5 and 6); and 3) the potential moderators of changes in movement behaviours (Research Area 4; Chapters 5 and 6) during the transition from primary to secondary school.

Table 2.1 Research topics and recommendations for Research Areas 2 to 4 within the VIRTUE framework

No.	Research area	Research topics and recommendations
2	Outcomes	• Examine relationships between time-use behaviours and all health-related outcomes (psychological and social) using appropriate statistical techniques: - Determine the relationships for the overall time-use composition and individual behaviours.
3	Time-use composition	• Prevalence: - Determine the average time spent in different time-use behaviours.
4	Determinants	• Identify correlates and determinants of the time-use composition.

Source: Pedišić, Dumuid & Olds (2017)

2.2 Conceptualisation of 24-hour movement behaviours

Twenty-four-hour movement behaviours can be defined as physical behaviours occurring over a 24-hour period across a movement intensity continuum (Figure 2.1) (Chaput et al. 2014). In health-related time-use research, these behaviours are commonly categorised into sleep, sedentary behaviour, and physical activity using the following criteria: 1) wakefulness (i.e., awake or not awake); 2) posture (i.e., lying, sitting, standing or stepping); and 3) relative energy expenditure (i.e., ≤1.5 metabolic equivalents (METs) for sedentary behaviour or >1.5 METs for physical activity) (Pedišić, Dumuid & Olds 2017). Definitions and measurement methods for these three behaviours are provided in Table 2.2. The three common types of movement behaviours (sleep, sedentary behaviour and physical activity) can be further categorised into different types of behaviours depending on the classification criteria used, for example, screen-based/non-screen-based sedentary time (Tremblay et al. 2017), and different domains of physical activity (e.g., organised/non-organised/active transport/active chores) (Kemp et al. 2020).

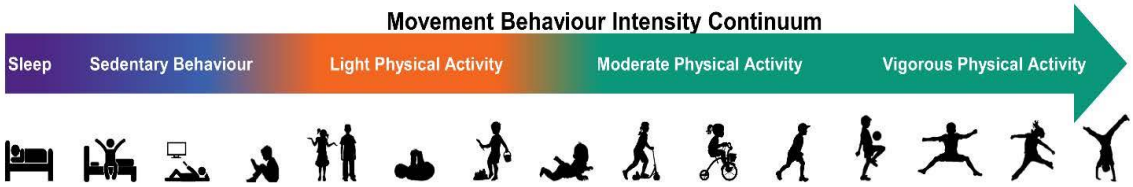

Figure 2.2 Movement behaviour intensity continuum

Image source: Kuzik (2020)

Table 2.2 Definitions and measurement methods of movement behaviours

Movement behaviour	Definition	Measurement methods	References
Sleep	A naturally recurring state of body and mind characterised by altered consciousness, relatively inhibited sensory activity, inhibition of nearly all voluntary muscles and reduced interactions with surroundings. It can be categorised into two dimensions: quantity (duration) and quality (e.g., efficiency, timing, consistency and continuity).	Objective/device-based methods: polysomnography, accelerometry Subjective methods: Proxy/self-report questionnaires, diaries/logs	Chaput, Saunders & Carson (2017); Buysse (2014)
Sedentary behaviour	Any waking behaviour characterised by an energy expenditure of ≤1.5 metabolic equivalent task (METs) while in a sitting, reclining or lying posture. It can be characterised using the SITT formula: • Sedentary behaviour frequency (number of sedentary bouts of certain duration) • Interruptions/breaks (intervals that separate the sedentary bouts) • Time (duration) • Type (mode of sedentary behaviour)	Objective/ device-based methods: Accelerometry, inclinometry, screen monitoring devices, direct observation Subjective methods: Proxy/self-report questionnaires, diaries/logs	Tremblay et al. (2017; 2010); Hardy et al. (2013)
Physical activity	Any body movement generated by the contraction of skeletal muscles that raises energy expenditure above resting metabolic rate. It can be characterised by multiple dimensions and domains: • Frequency (number of sessions or bouts or days) • Intensity (expressed in METs; light=1.6-2.9 METs, moderate=3.0-5.9 METs, vigorous=≥6.0 METs) • Time (duration) • Type • Domain (the context or reason for the physical activity)	Objective/device-based methods: Doubly-labelled water, heart rate monitoring, accelerometry, pedometry, direct observation Subjective methods: Proxy/self-report questionnaires, diaries/logs	Caspersen, Powell & Christenson (1985); Dollman et al. (2009); Loprinzi & Cardinal (2011)

2.2.1 Measuring 24-hour movement behaviours

As described previously in Section 2.2 (see Table 2.2), various measurement methods are available to assess sleep, sedentary behaviour and physical activity. Given that these movement behaviours are mutually exclusive components of the 24-hour cycle (Rosenberg et al. 2019; Pedišić, Dumuid & Olds 2017), it is important to measure them simultaneously using a single tool or instrument. This section discusses briefly two commonly used methods for assessing the full 24-hour movement behaviour composition in children and adolescents: 24-hour accelerometry (Katzmarzyk et al. 2013) and time-use diaries (Olds, Maher & Dumuid 2019).

i. 24-hour accelerometry

An accelerometer is a light-weight, wearable device that measures accelerations generated by the human body segment to which it is attached (e.g., waist- or wrist-worn) (Migueles et al. 2017). It is typically used to provide quantitative estimates of time spent in sedentary behaviour and different intensities of physical activity by applying cut-points developed for specific age groups (Hardy et al. 2013; Dollman et al. 2009); or to assess sleep-related behaviours in isolation of waking behaviours (Acebo et al. 1999). With recent advancements in accelerometry-based technology (e.g., wrist-worn, waterproof devices) (Troiano et al. 2014) and data processing and analysis methods (Migueles et al. 2019), the full 24-hour movement behaviour composition can now be assessed continuously over the same time period with a single device, reducing participant burden and research costs (Meredith-Jones et al. 2015). Furthermore, a 24-hour accelerometry protocol has been shown to significantly improve accelerometer wear time compliance (e.g., longer waking wear time) when compared to a traditional waking-hours only protocol (where participants were asked to remove the accelerometer at bedtime) (Tudor-Locke et al. 2015), thereby increasing the validity and reliability of movement behaviour estimates in free-living research.

Traditionally, the analysis of accelerometry data involves the reduction of acceleration signals into specific metrics (e.g., activity count, vector magnitude) that can be further classified into different behaviours using validated cut-points or algorithms (Barreira et al. 2015; Hildebrand et al. 2014). It is, however, important to note that most studies to date have used absolute- rather than relative-intensity cut-points, which is likely to result in some misclassification of movement behaviours (e.g., MVPA) (Haapala et al. 2020; Raiber et al. 2019). Recent research suggests that machine learning approaches may be more robust and valid for classifying accelerometer-measured movement behaviours than traditional cut-point approaches (Kuzik, Spence & Carson 2021; Ahmadi, Pfeiffer & Trost 2020). However, the machine learning approaches can be computationally demanding and the resulting models from laboratory-based trials may not always generalise well to free-living scenarios (Trost 2020). Nonetheless, there is some evidence showing that the resultant estimates from the application of unsupervised machine learning models are subject to less error compared to those of the supervised models (Thornton, Kolehmainen & Nazarpour 2022; van Kuppevelt et al. 2019), highlighting the former classification approach as a more appropriate method to use in quantifying movement behaviours in free-living settings.

The major limitation of accelerometry includes a lack of consensus regarding the data collection and processing criteria (e.g., placement site, epoch length, definitions of non-wear time and classification methods), which can influence the validity, comparability and reproducibility of movement behaviour estimates across studies (Burchartz et al. 2020; Migueles et al. 2017). Further, current accelerometry-based algorithms or approaches may not adequately measure certain types of activities (e.g., cycling) nor provide contextual information on the movement behaviours (e.g., settings and types) (Burchartz et al. 2020; Pedišić & Bauman 2015). Despite these methodological limitations, accelerometry remains the preferred measurement method in field settings due to its ability to collect large amounts of quantitative, multi-dimensional

movement data over an extended period of time, allowing for a more detailed examination of 24-hour movement behaviour patterns (Burchartz et al. 2020).

ii. Time-use diary

The time-use diary method has gained considerable attention in public health research due to its ability to capture both durations and characteristics of health behaviours over the course of a 24-hour day (Bauman, Bittman & Gershuny 2019). This measurement method requires participants to record their activities sequentially based on a defined time-slot length (e.g., every 15 min), or with self-reported start and finish times, throughout the specified observation period (e.g., a 24-hour period or longer) (Sullivan et al. 2020; Bauman, Bittman & Gershuny 2019). Time-use diaries are often designed to collect information on multiple fields, including the primary (main) and secondary activities performed, their location, and who the activities are performed with (Sullivan et al. 2020); and can be completed retrospectively (i.e., using a recall diary that records the previous day's activities) or prospectively (i.e., to be completed on a designated day in the near future) (Hunt & McKay 2015). In movement behaviour research, the diary activities are usually coded using an activity classification system that is linked to a compendium of energy expenditure (also known as MET-linkage), which allows the 'raw' activity records to be aggregated into different intensities and domains of behaviours (Chau et al. 2019).

A strength of the time-use diary method is its ability to collect contextual data on individual behaviours (Bauman, Bittman & Gershuny 2019). For example, it allows researchers to identify the distribution and sequencing of daily activities, as well as the time and location of their occurrence, which may be useful for examining trends, correlates and determinants of behaviours (Kelly et al. 2015). Additionally, the diary data are less prone to measurement bias or reporting errors than those collected through the traditional questionnaire approach, in which participants are asked to provide estimates for specific behaviours in an aggregated format (e.g., daily screen time) (Chau et al. 2019; van der Ploeg et al. 2010). Among children, a 24-hour

time-use diary has been shown to be comparable to other self-report questionnaires in terms of its reliability and validity in assessing daily activity behaviours (Ridley, Olds & Hill 2006). Nonetheless, the use of diaries can impose a significant burden on both participants and researchers, although this limitation may be partly overcome by using technologies (e.g., internet- or app-based instruments) (Sullivan et al. 2020; Bauman, Bittman & Gershuny 2019).

2.2.2 Prevalence of 24-hour movement behaviours in school-aged populations

Determining the prevalence of movement behaviours is essential not only for monitoring the health behaviour patterns of general populations, but also for identifying at-risk population groups, evaluating the effectiveness of existing intervention strategies and policies, and guiding future policies and practices in promoting healthy behaviours (Guthold et al. 2018). In public health research, this is commonly measured by examining adherence to national or global guidelines on movement behaviours. Since 2016, several countries (e.g., Canada, New Zealand and Australia) have released national 24-hour integrated movement guidelines for children and adolescents aged 5-17y (Australian Government Department of Health 2019; New Zealand Ministry of Health 2017; Tremblay et al. 2016). These guidelines reinforce the importance of adopting an integrated approach that targets movement behaviours across the whole day to promote healthy growth and development. Specifically, the guidelines provide recommendations for each individual movement behaviour in constructing a healthy 24-hour day (see Table 2.3 for the Australian guidelines).

Table 2.3 Australian 24-Hour Movement Guidelines for Children and Young People (5 to 17y)

Movement behaviour	Recommendations
Sleep	• An uninterrupted 9-11 h of sleep for those aged 5-13y and 8-10 h for those aged 14-17y. • Consistent bed and wake-up times.
Sedentary behaviour	• Limiting sedentary recreational screen time to no more than 2 h. • Breaking up long periods of sitting as often as possible.
Physical activity	• Accumulating ≥60 min of MVPA involving mainly aerobic activities. • Several hours of a variety of LPA.

MVPA=moderate- to vigorous-intensity physical activity; LPA=light-intensity physical activity.
Source: Australian Government Department of Health (2019)

A recent systematic review of 24-hour movement guideline adherence identified 19 cross-sectional studies that included school-aged children (aged 5-11y) and/or adolescents (aged 12-17y) (Rollo, Antsygina & Tremblay 2020). These studies showed that only a small proportion of individuals (children: 4.8%-10.8%; adolescents: 1.6%-9.7%; combined population: 2.6%-7.5%) met the overall 24-hour movement guidelines (i.e., met all three individual movement behaviour recommendations: sleep duration, sedentary recreational screen time and MVPA) (Rollo, Antsygina & Tremblay 2020). More recent longitudinal studies conducted in Finland (Leppänen et al. 2021) and Canada (Chemtob et al. 2020) also revealed a declining trend in the overall guideline adherence during childhood and adolescence. Using data collected from an Australian population-derived sample, Watson et al. (2021) found that the overall guideline adherence varied between self-report (n=1,270; mean age=11.99y) (20.3% based on 24-hour time-use recall data for all three behaviours) and device-based measures of movement behaviours (n=927; mean age=11.97y) (12.0% based on accelerometer-derived sleep and MVPA and time-use recall data for screen time), largely due to differences in the estimates of MVPA guidelines adherence between the two measures (77.4% vs. 48.2%). This demonstrates the influence of measurement methods in assessing guideline adherence and should be taken into consideration in the planning of future research, especially for studies that aim to monitor the trends in movement behaviour over time.

In addition to examining guideline adherence, it is important to determine the distribution of movement behaviours over the 24-hour period, which can be referred to as the 24-hour movement behaviour composition. This information provides a foundation for the development of time-use research in different areas; for example, identifying the parts of the composition that are most critical for targeting in interventions for the population of interest, and determining the optimal movement behaviour composition that is realistically attainable and sustainable over long periods of time (Pedišić, Dumuid & Olds 2017).

A recent compositional analysis of 24-hour waist-worn accelerometry data from the International Study of Childhood Obesity, Lifestyle and the Environment (ISCOLE) showed that children aged 9-11y (n=5,759) spent an average of 9 h/day (37.4% of day) sleeping, 8.7 h/day (36.5% of day) being sedentary, 5.3 h/day (22.2% of day) in LPA, 41 min/day (2.9 % of day) in moderate-intensity physical activity (MPA), and 15 min/day (1.0% of day) in vigorous-intensity physical activity (VPA) (Dumuid et al. 2017). Differences in movement behaviour composition were observed across the 12 participating countries in ISCOLE (including Australia), with compositional means ranging between 8.5-9.6 h/day (35.4%-40.0% of day) for sleep, 8.1-9.6 h/day (33.8%-40.0% of day) for sedentary time, 4.8-5.8 h/day (20.0%-24.2% of day) for LPA and 43-69 min/day (3.0%-4.8% of day) for MVPA (see Table 2.4 for country-level data) (Dumuid et al. 2018a). Notably, Australian children were found to sleep longer, be less sedentary, and engage in a moderate amount of physical activity compared to children from other countries. To the candidate's knowledge, there is still a lack of longitudinal studies describing changes in 24-hour movement behaviour composition among school-aged populations in both the global and Australian context.

Table 2.4 Compositional means of time spent in 24-hour movement behaviours among 9 to 11-year-old children by participating countries in the ISCOLE study

Country	Sample size	Sleep (h/day)	Sedentary time (h/day)	LPA (h/day)	MVPA (min/day)
Australia	577	9.6	8.1	5.2	63
England	579	9.7	8.5	4.9	62
Canada	555	9.3	8.7	5.1	56
Finland	523	8.7	9.1	5.0	69
Portugal	508	8.5	9.5	5.1	53
United States	542	9.0	8.9	5.3	48
Brazil	526	8.8	8.6	5.8	55
Colombia	531	8.9	8.5	5.6	65
China	531	8.9	9.6	4.9	43
India	523	8.7	8.8	5.8	45
South Africa	561	9.4	8.3	5.4	60
Kenya	525	8.8	8.5	5.7	67

LPA=light-intensity physical activity; MVPA=moderate- to vigorous-intensity physical activity.
Source: Dumuid et al. (2018a)

2.3 Psychosocial health and its prevalence in school-aged population

There is no universal definition of psychosocial health; however, it is typically used as an umbrella term to cover both mental and social dimensions of health, which are essential components for supporting an individual's optimal health functioning (World Health Organization 1948). The World Health Organization (1999) defines mental health as "a state of well-being in which an individual realises his or her abilities, can cope with the normal stresses of life, can work productively and fruitfully, and is able to make a contribution to his or her community". In childhood and adolescence, mental health conditions are commonly classified into two broad dimensions, namely internalising and externalising problems (Patalay et al. 2017). Internalising problems refer to any over-inhibited or internally-focused behavioural problems (e.g., anxiety, depression), whereas externalising problems include the disinhibited or externally-focused type of behavioural problems (e.g., conduct problems, hyperactivity) (Willner, Gatzke-Kopp & Bray 2016). On the other hand, social health is commonly defined as the ability to develop and maintain meaningful interactions with others (Waters et al. 2012), which includes any voluntary actions intended to benefit others (including helping, sharing and comforting others) (Dunfield 2014).

Mental disorders (e.g., major depressive disorders, anxiety disorders) are one of the leading causes of disease burden among children aged 5-14y (Baranne & Falissard 2018), affecting 14.3% of the population globally (Polanczyk et al. 2015). Many mental disorders emerge during childhood or adolescence, but often remain undetected until later in life (Kessler et al. 2007). National data from the Young Minds Matter survey in 2013-2014 showed that nearly one in seven (13.9%) Australian children and adolescents aged 4-17y were assessed as having mental disorders in the 12 months preceding the survey, which is equivalent to 560,000 children nationally (Lawrence et al. 2016). Attention-deficit/hyperactivity disorder was the most common mental disorder reported among the population (7.4%), followed by anxiety disorders (6.9%), major depressive disorders (2.8%) and conduct disorder (2.1%) (Lawrence et al. 2016). Approximately 17% of children and adolescents also reported using services for emotional or behavioural problems during the 12-month period (Johnson et al. 2016). Using 10-year longitudinal data (2004-2014) from the Longitudinal Study of Australian Children (LSAC), Christensen et al. (2017) found that there was an overall decline in children's emotional and behavioural problems from early childhood (ages 4-5y) to mid-adolescence (ages 14-15y). On the other hand, Putra et al. (2021) found a hump-shaped pattern in their prosocial behaviour development, which appeared to increase during childhood but declined in early adolescence. Given the prevalence of psychosocial health problems and their profound effect on children's health and development, including their educational achievement, substance use and abuse, violence, reproductive and sexual health (Patel et al. 2007), identifying associated modifiable risk factors and ideal times to intervene is of critical importance.

2.4 The transition from primary to secondary school: why is it important?

The transition from primary to secondary school (hereinafter referred to as the school transition) is regarded as a major life event for most children worldwide, typically occurring between the ages of 10-14y (Evans, Borriello & Field 2018). Despite variations in education systems around the world, the school transition is generally marked by significant changes in the learning

environment, academic expectations and social interactions (Hanewald 2013). This transition period is also considered a time of vulnerability as it coincides with the onset of pubertal development, which is characterised by rapid physical, psychological and emotional changes (Patton & Viner 2007); as well as the emergence of many psychological disorders (e.g., anxiety disorders and impulse-control disorders) (Kessler et al. 2005).

Previous research has shown that while many children adapt well to this transition, it could be a particularly demanding and problematic period for others, especially those from socio-economically disadvantaged backgrounds or with poorer psychosocial health profiles (e.g., low self esteem, high levels of mental health difficulties) (Maguire & Yu 2015; West, Sweeting & Young 2010). There is also evidence that children's experiences of the school transition can have a significant impact on their psychosocial and intellectual development (Hanewald 2013; Waters et al. 2012; West, Sweeting & Young 2010). For example, children with negative transition experiences are more likely to have higher levels of social and emotional problems and lower educational attainment (Waters et al. 2012; West, Sweeting & Young 2010), and these impacts are likely to persist throughout and beyond the secondary school years (West, Sweeting & Young 2010). This school transition phase is therefore a critical period for supporting children to continue developing holistically.

In Australia, the primary school years begin with a foundation year (also known as Kindergarten or Preparatory) and are followed by Years 1 to 6 in all states and territories except South Australia (Years 1 to 7); whereas the secondary school years begin with Year 7 (or Year 8 In South Australia) and end with Year 12 (Australian Curriculum, Assessment and Reporting Authority 2021). Most Australian children begin the first year of primary school when they are aged 4 to 5y (Australian Curriculum, Assessment and Reporting Authority 2021); hence, the transition to secondary school usually occurs around the age of 11-12y. This transition may or may not require a change in school, depending on the type of primary school system. For

example, children enrolled in a primary-only school system (which provides only primary education and accounts for 65.5% of all registered schools in 2020) (Australian Bureau of Statistics 2021) are required to move to a new school for secondary education. Whereas those enrolled in a combined school system (which provides both primary and secondary education and accounts for 14.3% of all registered schools in 2020) (Australian Bureau of Statistics 2021) can continue their secondary education at the same school. Data from a population survey showed that approximately 15% of Australian children experienced difficulties with the transition to a new secondary school (e.g., difficulties with making new friends, missing friends from their previous school and being required to do more homework), which appeared to be related to their pre-transition socio-emotional well-being status (Maguire & Yu 2015). Little is known, however, about the transition experiences of children who do not change schools during this school transition phase.

2.5 The school transition and its association with 24-hour movement behaviours

Schools are recognised as an important setting for promoting healthy behaviours among children and adolescents, with increasing evidence demonstrating the influence of the school environment on their movement behaviour patterns (Bowers & Moyer 2017; Morton et al. 2016). Of particular interest is the differences in environmental characteristics between the primary and secondary school settings (e.g., physical, social and policy) (Harrison et al. 2016; De Meester et al. 2014), which may lead to significant behavioural changes as children make the transition to secondary school.

A recent systematic review identified 11 articles that examined changes (n=7) or tracking (n=4) in sedentary behaviour across the primary to secondary school transition (Pearson et al. 2017). Overall, there was consistent evidence of an increase in both self-report (predominantly screen-based behaviours such as television viewing and video games use) and accelerometer measures of sedentary behaviour during the school transition. The analysis of change using accelerometer

data revealed an increase of approximately 10 to 20 min/day per year in overall sedentary time between the primary and secondary school years (Pearson et al. 2017). The tracking coefficient for screen-based sedentary behaviour typically ranged between 0.3 and 0.5 and was relatively consistent across behaviour types and follow-up durations (Pearson et al. 2017). This review stated, however, that it remains unclear whether such behavioural changes are attributable to the school transition *per se*. It was recommended that further research be conducted to identify the aspects of the school environment that may influence children's sedentary behaviour and examine changes in the accumulation patterns of sedentary time during this school transition period (Pearson et al. 2017).

It is important to note that the aforementioned review (Pearson et al. 2017) did not consider changes in the other components of 24-hour movement behaviours (i.e., physical activity and sleep) that are co-dependent on each other due to the finite nature of time. To provide a more detailed understanding of children's daily movement behaviour patterns during the school transition period, a systematic review was conducted as part of this thesis to identify studies that reported changes in physical activity, sedentary behaviour and sleep, both individually (i.e., changes within each individual movement behaviour) and collectively (i.e., changes in the combinations or compositions of movement behaviours) (see Chapter 3; Chong et al. 2020). This review identified six articles that met the pre-defined eligibility criteria; five examined changes in time spent in physical activity only (Barr-Anderson et al. 2017; D'Haese et al. 2015; De Meester et al. 2014; Cooper et al. 2012; Jago, Page & Cooper 2012), while one examined concurrent changes in physical activity and sedentary behaviour (Marks et al. 2015). There is limited but consistent evidence of a decrease in total daily physical activity and during specific time periods (e.g., after-school or leisure time period) over the school transition. A concurrent increase in sedentary behaviour was also observed in the single study that explored changes in both behaviours within the same sample (Marks et al. 2015). This review also highlighted a

dearth of research investigating changes in sleep duration and, more importantly, concurrent changes in all three movement behaviours over a 24-hour period (Chong et al. 2020).

In view of the recently introduced 24-hour movement paradigm and the growing evidence of associations between the movement behaviour composition and health outcomes (see Section 2.7.5) (Rollo, Antsygina & Tremblay 2020; Sampasa-Kanyinga et al. 2020), additional research using an integrated approach is warranted to examine changes in children's 24-hour movement behaviour composition that accompany the school transition.

2.5.1 Potential moderators of changes in movement behaviours during the school transition

Information about the moderators of changes in movement behaviours is essential for the development of effective behavioural change interventions. A full-text screening of the articles included in the two systematic reviews described in Section 2.5 (Chong et al. 2020; Pearson et al. 2017) was conducted to identify relevant literature in this topic area. Nine of the twelve articles that examined changes in durations of physical activity and/or sedentary behaviour during the school transition included an analysis of potential moderators of the behavioural changes (Barr-Anderson et al. 2017; Corder et al. 2015; D'Haese et al. 2015; Marks et al. 2015; De Meester et al. 2014; Rutten, Boen & Seghers 2014; Atkin, Corder & van Sluijs 2013; Cooper et al. 2012; Jago, Page & Cooper 2012). These articles included data from 4,541 children across four countries (Australia, Belgium, United Kingdom, United States). The analysed factors can be grouped into six categories following the VIRTUE framework's classification of correlates/determinants (Pedišić, Dumuid & Olds 2017): socio-demographic, health and functioning, social and cultural, behavioural and lifestyle, environmental, and skills and abilities.

i. Socio-demographic factors

Four articles investigated whether socio-demographic factors (sex, race/ethnicity, parent education, poverty index, residential location) moderated changes in physical activity and/or sedentary behaviour (Barr-Anderson et al. 2017; Corder et al. 2015; De Meester et al. 2014; Rutten et al. 2014).

De Meester et al. (2014) (n=420) found that a child's sex had no effect on changes in both device-based (e.g., accelerometer-measured weekday MVPA) and subjective (e.g., time spent in extracurricular physical activity) measures of physical activity. On the other hand, Rutten et al. (2014) (n=472) revealed that sex had a moderating effect on changes in education-related sedentary behaviour but not recreational screen-based sedentary behaviour (i.e., television viewing, computer use), with girls reporting a greater increase in time spent doing homework than boys. Corder et al. (2015) (n=990) also reported that accelerometer-measured MVPA declined more steeply in boys than girls across the school transition period.

Barr-Anderson et al. (2017) (n=643) demonstrated that race/ethnicity, parental education and poverty index had no effect on the change in accelerometer-measured total physical activity levels. Similarly, Corder et al. (2015) found parental education had no effect on changes in accelerometer-measured sedentary time, LPA and MVPA. They did, however, observe a greater decline in MVPA among rural children compared to urban children (Corder et al. 2015).

ii. Health and functioning factors

Two articles examined whether body weight status moderated changes in physical activity and/or sedentary behaviour and their results were mixed (Corder et al. 2015; Rutten et al. 2014). Corder et al. (2015) found that while children who were overweight/obese spent more time sedentary and less time in MVPA than their normal-weight counterparts across the four-year study period, the extent of behavioural changes did not differ significantly between the two

groups. On the other hand, Rutten et al. (2014) observed that children who were normal weight reported a greater increase in time spent on homework, but a smaller increase in recreational computer screen use (only in boys) compared to those who were overweight/obese.

iii. Social and cultural factors

Jago, Page and Cooper (2012) (n=626) reported that peer-related factors were specifically associated with changes in accelerometer-measured physical activity among girls but not boys. Notably, increased friend support for physical activity and number of friends were significantly associated with an increase in girls' afterschool and weekend MVPA during the transition period.

iv. Behavioural and lifestyle factors

Cooper et al. (2012) (n=469) reported that the mode of travel to school moderated the changes in accelerometer-measured physical activity. Significant increases in weekday MVPA were observed among children who walked to school at both primary and secondary school time points (walk-walk; +11.4%), as well as those who changed from passive to active travel mode (car travel-walk; +16.1%). Whereas children who changed from active to passive travel mode (walk-car travel) experienced a 15.5% decrease in weekday MVPA during the transition period.

v. Environmental factors

Five articles examined whether environmental factors (home, neighbourhood and school environment characteristics) moderated changes in physical activity and/or sedentary behaviour (Barr-Anderson et al. 2017; Marks et al. 2015; D'Haese et al. 2015; De Meester et al. 2014; Atkin, Corder & van Sluijs 2013).

In relation to the home environmental factors, Atkin, Corder and van Sluijs (2013) (n=357) found that children who had a television in their bedroom reported a greater increase in screen

time compared to those who did not. Conversely, Barr-Anderson et al. (2017) reported that children with the highest access to physical activity equipment at home experienced a steeper decline in accelerometer-measured total physical activity level than those who had the least access, though this was observed only among Black children, but not White and Hispanic children.

With respect to the effect of neighbourhood environment, D'Haese et al. (2015) (n=321) found that the associations between neighbourhood environmental characteristics and changes in physical activity were more consistent among boys than girls. Among boys, an increase in parent-perceived availability of walking and cycling infrastructure and street connectivity were associated with a greater increase in time spent on cycling for transport during leisure time and total daily step counts. An increase in child-perceived neighbourhood aesthetics was also associated with greater time spent in active transportation to school. Among girls, an increase in parent-perceived availability of walking and cycling infrastructure and a decrease in child-perceived distance to recreation facilities were associated with a greater increase in time spent on cycling for transport and sports during leisure time.

In the context of school environment, De Meester et al. (2014) reported that positive changes in school environmental characteristics (e.g., active schoolyards and playgrounds and health education policies) were associated with increases in extracurricular physical activity duration and weekday step counts. On the other hand, Marks et al. (2015) (n=243) found that children who moved to a new secondary school spent more time on recreational screen use during weekdays and weekends than children who stayed at the same school, though no significant differences were observed in the accelerometer measures of physical activity and sedentary time between the two groups.

vi. Skills and abilities factors

Barr-Anderson et al. (2017) reported that children's personal attributes (self-efficacy, barriers to physical activity and enjoyment of physical activity) significantly predicted changes in physical activity, though associations varied by race/ethnicity. Among Black children, those with the highest level of self-efficacy had a smaller decline in total physical activity levels than those with the lowest level of self-efficacy. Among White children, those who reported the most barriers to physical activity and enjoyment of physical activity had a greater decline in total physical activity levels than those who reported the fewest barriers and least enjoyment. Among Hispanic children, those who expressed the greatest level of enjoyment when engaged in physical activity reported a smaller decline in total physical activity levels than those who expressed the least amount of enjoyment.

2.5.2 Summary of potential moderators of changes in movement behaviours during the school transition

Overall, there is evidence suggesting that environmental factors (particularly neighbourhood and school environmental characteristics) may play a critical role in preventing unhealthy changes in movement behaviours during the school transition. There is inconsistent evidence regarding the influence of socio-demographic (e.g., sex, parent education) and health and functioning factors (body weight status) on behavioural changes, which may be partly explained by the differences in movement behaviour measures used across studies. It is not possible to draw conclusions about other factors (e.g., peer-related and lifestyle factors) due to the scarcity of data. Nonetheless, these findings should be interpreted cautiously as the majority of studies focused exclusively on associations with a single movement behaviour. Due to the co-dependent nature of movement behaviours, a factor affecting one behaviour is likely to have an impact on the remaining behaviours within the 24-hour composition (Pedišić, Dumuid & Olds 2017). Therefore, further research is needed to re-examine the influence of these factors on the overall 24-hour movement behaviour composition using an integrated approach.

2.6 The school transition and its association with psychosocial health

The transition from primary to secondary school has been identified as a stressful period that can have both short- and long-term effects on children's psychosocial health (Viner et al. 2012; West, Sweeting & Young 2010). As discussed in Section 2.4, this period often involves simultaneous changes in many aspects of a child's life (e.g., academic environment and social interactions) and coincides with other puberty-related developmental changes (Hanewald 2013; Patton & Viner 2007), which may contribute to increased feelings of loneliness and isolation, as well as negative or disruptive behaviours in some children (Lester & Cross 2015). Additionally, social and emotional issues (e.g., peer relationships, bullying) are identified as the primary concerns of children during the school transition phase (Topping 2011). Despite that, the empirical evidence is equivocal as to whether the school transition negatively affects children's psychosocial health (e.g., internalising and externalising problems, anti-social behaviour) (Evans, Borriello & Field 2018). For example, in the Australian context, a previous study showed that the majority of children reported stable (55%) or improved psychological functioning (20%) over the transition period (Wallis & Barrett 1998). However, the study by Lester and Cross (2015) found that mental and emotional problems significantly increased, while peer problems and pro-social tendencies significantly decreased following the transition to secondary school.

One possible explanation for these mixed results could be due to individual differences in expectations and/or experiences with the school transition (Evans, Borriello & Field 2018). Existing literature shows that children who express more worries or have negative expectations about the transition are likely to experience a poorer transition than their peers, which is often related to greater and negative psychological changes (e.g., higher levels of depression, anxiety and loneliness) (Waters, Lester & Cross 2014; Waters et al. 2012; West, Sweeting & Young 2010). A recent review also identified other factors that may contribute to changes in children's psychosocial functioning during the school transition, such as parental and teachers' support,

peer relationships, school climate, and bullying-victimisation (Spernes 2020). For example, an Australian study found that school climate factors, such as feeling safe at school, feeling connected to school and peer support, were all protective factors of children's mental and emotional wellbeing over the transition period (Lester & Cross 2015). Further research is warranted to examine how these variables may interact to influence children's psychosocial health across the school transition, particularly among understudied population subgroups (e.g., children who do not change schools during this transition (Nielsen et al. 2017)).

2.7 Associations between 24-hour movement behaviours and psychosocial health

Twenty-four hour movement behaviours (sleep, sedentary behaviour and physical activity) have been recognised as key determinants of health and wellbeing across the lifespan (Rosenberg et al. 2019; Okely et al. 2017; Tremblay et al. 2016). This section summarises evidence and identifies research gaps regarding individual and combined associations between movement behaviours and psychosocial health outcomes in children and adolescents aged 5 to 17y.

2.7.1 Sleep and psychosocial health

A systematic review by Chaput et al. (2016) has synthesised data from 62 studies exploring the association between sleep duration and psychosocial health outcomes, including stress, anxiety, depressive symptoms and mental health. The main conclusion was that a longer sleep duration was associated with better health outcomes. An updated review conducted in 2018 using the same search strategy as Chaput et al.'s (2016) review has identified 27 additional studies in this area of research, demonstrating that there is continued evidence of a favourable association between longer duration of sleep and psychosocial health (Australian Government Department of Health 2019). However, the quality of evidence was rated as very low as it relied heavily on cross-sectional studies (67 of the 89 studies included in the reviews) and the use of self-report measures without no psychometric properties reported (Australian Government Department of Health 2019; Chaput et al. 2016). It was recommended that further high-quality studies using

more accurate measures of sleep duration (e.g., accelerometry) are needed to better understand the associations between sleep duration and psychosocial health (e.g., the existence of dose-response relationships) (Chaput et al. 2016).

2.7.2 Sedentary behaviour and psychosocial health

Several systematic reviews and meta-analyses have found that high levels of sedentary behaviour were unfavourably associated with several psychosocial health outcomes (e.g., depression, anxiety, behavioural conduct/prosocial behaviour, psychological distress) (Stanczykiewicz et al. 2019; Carson et al. 2016a; Hoare et al. 2016). However, the evidence was largely synthesised from studies that examined only time spent in screen-based sedentary behaviours (e.g., television viewing, computer and video game use), which do not account for the majority of sedentary behaviour in most children (Straker et al. 2016), and may not the primary contributors to the population's high sedentary time (Hoffmann et al. 2019). While there has been an increasing use of accelerometry to quantify total sedentary behaviour, there is limited and mixed evidence for the association between the overall volume or patterns of sedentary behaviour and psychosocial health (Stanczykiewicz et al. 2019; Carson et al. 2016a; Cliff et al. 2016). Therefore, it remains inconclusive as to whether the association of sedentary behaviour with psychosocial health is explained by the amount of time spent sedentary or exposure to specific types of sedentary behaviour.

It has been suggested that different types of sedentary behaviour may have different impacts on psychosocial health, with screen-based sedentary behaviours being more consistently linked to negative health outcomes than non-screen-based sedentary behaviours (e.g., reading, passive transport) (Straker et al. 2016; Suchert, Hanewinkel & Isensee 2015). A recent umbrella review by Stiglic and Viner (2019) found moderately strong evidence for an association between screen time and greater depressive symptoms; and weak evidence for an unfavourable association with other psychosocial health outcomes (e.g., behaviour problems, anxiety, hyperactivity and

inattention). There appeared to be a non-linear dose response association between screen time and psychosocial health, with a decreasing risk of depression observed when screen time was below 2 h/day (the lowest risk was observed at 1 h/day, i.e. a 12% reduction in risk) and a continuously increasing risk observed above 2 h/day compared to zero screen time (Liu, Wu & Yao 2016). Nonetheless, recent research demonstrates that the associations between screen time and health outcomes vary by the types or contexts of screen-use behaviours. Notably, interactive (e.g., playing video games) and passive (e.g., television viewing) forms of recreational screen use, but not educational screen time (e.g., computer use for homework), were found to be associated with greater psychosocial problems, although the effect sizes were generally small (Sanders et al. 2020; Babic et al. 2017). It is worth noting that the majority of screen time research focuses on traditional forms of screen-based sedentary behaviour (e.g., television viewing), with little available information on the health effects of newer types of screen use, which may occur in non-sedentary postures (e.g., active gaming consoles) (Harrington et al. 2021; Thomas et al. 2020). Additional research is needed to ascertain the individual and combined effects of various types and contexts of screen use on psychosocial health to gain a more holistic understanding of the health implications of screen time.

2.7.3 Physical activity and psychosocial health

An umbrella review by Biddle et al. (2019) (including 42 systematic reviews and meta-analyses) found that while physical activity was shown to be beneficially associated with mental health outcomes (e.g., depression, anxiety and self-esteem), there was a lack of supporting evidence for both temporal sequencing and dose-response relationships. There was partial support for a causal association with depression, but not with self-esteem; although experimental evidence indicated positive changes in these outcomes as a result of physical activity intervention (Biddle et al. 2019). This concurs with other systematic reviews demonstrating the beneficial effects of physical activity interventions on a range of mental

health and wellbeing outcomes (e.g., depression, stress and anxiety) (Hale et al. 2021; Andermo et al. 2020; Rodriguez-Ayllon et al. 2019).

In terms of the associations for different intensities of physical activity, there were inconsistent associations between MVPA and behavioural conduct/prosocial behaviour, psychological distress and self-esteem; and no associations between LPA and VPA and psychological distress, based on a small number of accelerometer-based studies (n=6) identified in Poitras et al.'s (2016) systematic review. The heterogeneity in accelerometer data collection and processing methods (e.g., sampling intervals, intensity cut-points) may have contributed to the inconsistency in results (Poitras et al. 2016), highlighting the importance of developing or adopting evidence-based approaches to inform accelerometer-related methodological decisions in this area of research.

As with sedentary behaviour, it has been suggested that the types or domains of physical activity may moderate the association between physical activity and psychosocial health. For example, a meta-analysis demonstrated that the association of physical activity with mental health was not consistent across life domains, with significant and positive association observed for leisure-time physical activity and participation in school sport, but not for household physical activity or participation in physical education (White et al. 2017). To gain a better understanding of the mechanisms underlying the associations, additional research is needed to investigate the effects of different types and contexts (physical and social) of physical activity, as well as individual's activity preferences, on psychosocial health (Biddle et al. 2019).

2.7.4 Summary on the associations between individual movement behaviours and psychosocial health

Overall, there is substantial evidence that sleep and physical activity are beneficial, while sedentary behaviour (particularly screen-based behaviours) is detrimental to children and

adolescents' psychosocial health. However, these findings should be interpreted with caution as most studies have examined the health associations of each behaviour in isolation, disregarding the potential synergistic effects resulting from interactions between the three behaviours that comprise the whole 24-hour period (Chastin et al. 2015; Pedišić 2014). Saunders et al.'s (2016) systematic review identified only four studies that investigated the associations between combinations of all three movement behaviours and health outcomes in school-aged populations, and none of these included any psychosocial health outcomes. Because the total time spent in movement behaviours during a 24-hour period is finite, it is evident that these behaviours are intrinsically linked and that their associations with health should be considered relative to one another (Pedišić, Dumuid & Olds 2017; Chastin et al. 2015). Further research is warranted to understand how the combination or composition of movement behaviours during a 24-hour period may affect psychosocial health.

Another important methodological limitation in this topic area is that the traditional multivariate analyses examining the associations between movement behaviours and health outcomes have not been able to account for all movement behaviours in a single model due to the perfect multi-collinearity between the behaviours (Dumuid et al. 2018b). It is therefore important to re-examine potentially biased findings using more appropriate statistical approaches, such as the CoDA method (Pedišić, Dumuid & Olds 2017; Chastin et al. 2015). CoDA is a statistical methodology developed to deal with any type of compositional data (e.g., time-use data) that consists of mutually exclusive and exhaustive components and conveys only relative information (Aitchison 1982). It enables the analysis of the association of an individual component to be considered relative to the remaining components of the composition, as well as the association of the overall composition by considering the relative information between all components of the composition. A more detailed explanation of the CoDA method and its application to movement behaviour data can be found in Chapter 4 (Section 4.4).

2.7.5 Associations between the combinations and compositions of movement behaviours with psychosocial health

Since the introduction of the new 24-hour movement paradigm and associated public health guidelines, there has been an increase in the amount of research examining the associations between the combinations of movement behaviours during a 24-hour day and health outcomes across different populations (Rollo, Antsygina & Tremblay 2020). Recent systematic reviews of cross-sectional studies on the potential health benefits of adherence to the 24-hour movement guidelines found that meeting all three individual movement behaviour recommendations (i.e., sleep duration, sedentary recreational screen time and MVPA) concurrently was associated with better psychosocial outcomes (e.g., lower levels of emotional problems and depressive symptoms) when compared to meeting none of the recommendations among children and adolescents (Rollo, Antsygina & Tremblay 2020; Sampasa-Kanyinga et al. 2020). There was also evidence of a dose-response gradient between the number of recommendations met and more positive mental health outcomes (Sampasa-Kanyinga et al. 2020). Additionally, meeting the recommendation for sleep duration or sedentary recreational screen time was more strongly associated with mental health outcomes than meeting the MVPA recommendation (Sampasa-Kanyinga et al. 2020).

While those findings provide valuable insight into the health implications of certain combinations of movement behaviours, they should be interpreted with caution. The analysis of movement guideline adherence did not consider the full spectrum of 24-hour movement behaviours due to the lack of quantitative recommendations available for certain types of behaviours (e.g., LPA and total sedentary time). The dichotomisation of duration data for movement behaviours (e.g., meeting vs. not meeting the guidelines) may also reduce the sensitivity in detecting their associations with health outcomes (Rollo, Antsygina & Tremblay 2020).

To the best of candidate's knowledge, only two cross-sectional studies have examined the associations between the full 24-hour movement behaviour composition (i.e., time spent in sleep, sedentary time, LPA and MVPA) and psychosocial health outcomes in school-aged children and adolescents (Fairclough et al. 2021; Carson et al. 2016b). A summary of the research methodology and findings of these studies can be found in Table 2.5. While both studies found a significant association between the movement behaviour composition and psychosocial health, the results were mixed for the relative associations of individual movement behaviours. Carson et al. (2016b) found that more time spent in LPA and less time in sleep (relative to other behaviours) were associated with higher levels of total psychosocial difficulties. However, no significant associations were observed for total sedentary time and MVPA relative to other behaviours (Carson et al. 2016b). On the other hand, Fairclough et al. (2021) reported that higher total sedentary time relative to other behaviours was associated with greater internalising problems (full sample) and lower levels of prosocial behaviour (primary school children only), with no significant associations observed for the other movement behaviours (sleep, LPA and MVPA). The mixed results may be partially explained by the differences in population characteristics (e.g., age range) and measurement methods of movement behaviours between the two studies (e.g., waist- vs. wrist-worn accelerometry, count-based vs. raw acceleration-based data reduction approaches).

2.7.6 Summary on the associations between the composition of movement behaviours and psychosocial health

The limited cross-sectional evidence suggests that the time-use composition of 24-hour movement behaviours was associated with children's and adolescent's psychosocial health. Additional high-quality research using longitudinal or experimental designs, as well as valid measures of movement behaviours and psychosocial health, is warranted to confirm this association and elucidate its nature in different population subgroups (Rollo, Antsygina & Tremblay 2020; Sampasa-Kanyinga et al. 2020). Given the evidence for the unique influence of

specific types or domains of movement behaviours on psychosocial health (as described in Sections 2.5.2 and 2.5.3), it is important for future research to measure and analyse both intensity- and domain-specific movement behaviours to further clarify the association between movement behaviours and psychosocial health.

Table 2.5 Summary of studies examining the associations between 24-hour movement behaviours and psychosocial health outcomes in school-aged populations using compositional data analysis

Authors	Study design	Country	Participant characteristics	Measurements of movement behaviours	Psychosocial health outcomes	Main findings
Carson et al. (2016b)	Cross-sectional	Canada	N=3924; age range: 6-17y	Sleep: Estimated duration in a 24-hour period reported by parents/guardians (for aged 6-11y) or participants (for aged 12-17y) SED, LPA and MVPA: Waist-worn accelerometer (Actical, Philips Respironics)	Total behavioural strengths and difficulties score (assessed using the parent-report version of SDQ)	The movement behaviour composition was significantly associated with total difficulties score. Relative to other behaviours, sleep was negatively, while LPA was positively associated with total difficulties scores. No significant associations were observed for other behaviours.
Fairclough et al. (2021)	Cross-sectional	United Kingdom	N=359; mean age: 11.5y; 50.7% girls Primary school sub-sample: 210; mean age: 10.4y; 49.0% girls	Sleep, SED, LPA and MVPA: Wrist-worn accelerometer (ActiGraph GT9X, ActiGraph)	Self-esteem (assessed using the Rosenberg Self-Esteem Scale) Depression (assessed using the Mood and Feelings Questionnaire)	No significant associations were observed for the overall movement behaviour composition for the primary, secondary and combined school samples. No significant associations were observed for the overall movement behaviour composition for the primary, secondary and combined school samples.

	Secondary school sub-sample: 149; mean age: 13.0y; 53% girls	Emotional and behavioural problems (assessed using the self-report version of SDQ)	The movement behaviour composition was significantly associated with internalising problems in the combined school sample, and prosocial behaviour in the primary school sample. Relative to other behaviours, SED was positively associated with internalising problems in the combined school sample, and negatively associated with prosocial behaviour in the primary school sample. No significant associations were observed for other behaviours.

SED=sedentary time; LPA=light-intensity physical activity; MVPA=moderate- to vigorous-intensity physical activity; SDQ=Strengths and Difficulties Questionnaire.

2.8 Research gaps

This literature review has identified several research gaps that need to be addressed to better understand the development of 24-hour movement behaviours and their associations with psychosocial health among school-aged children and adolescents. As discussed in Section 2.1, the transition from primary to secondary school is a critical period of development for most children due to the accompanying changes (e.g., academic and biological) that may have a significant impact on health and wellbeing. Notably, there is evidence that children increase their sedentary time and decrease their physical activity during this transition period. However, most research to date has focused on the change in a particular behaviour (e.g., physical activity) without considering its interactions with other co-dependent behaviours (e.g., sleep, sedentary behaviour) that collectively comprise the 24-hour day (Chong et al. 2020). This has limited our understanding of how children re-allocate their time between movement behaviours in the context of a 24-hour period as they make the transition to secondary school.

In addition, although a plethora of studies have established links between individual movement behaviours and psychosocial health during childhood and adolescence, none have focused on the school transition period. Furthermore, only a few cross-sectional studies have investigated the combined associations between 24-hour movement behaviours and psychosocial health using CoDA to account for the compositional properties of movement behaviour data (Fairclough et al. 2021; Carson et al. 2016b). It is also unclear whether such associations may be influenced by the types or domains of movement behaviours (e.g., recreational screen use), which appear to have differing effects on psychosocial health.

This thesis aims to bridge the aforementioned gaps by using CoDA to investigate changes in 24-hour movement behaviours and their associations with psychosocial health during the school transition period (see Chapters 5 to 7). The research outcomes may inform strategies to assist children in developing and/or maintaining healthy movement behaviour patterns, and more

importantly, to promote positive psychosocial development during the school transition period. It may also contribute to strengthen and expand the evidence base on the collective influence of 24-hour movement behaviours on children's psychosocial health.

2.9 References

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Chapter 3: Changes in physical activity, sedentary behaviour and sleep across the transition from primary to secondary school: a systematic review

Chapter 2 provided an overview of the extant literature highlighting the research gaps explored through this thesis. As described in Section 2.5, a systematic literature review was performed to identify and review studies that explored changes in physical activity, sedentary behaviour and sleep during the transition from primary to secondary school. This chapter contains the published systematic literature review, which addressed part of the following research question:

Research Question 1:

How does the distribution of time spent in different intensities and domains of 24-hour movement behaviours change across the transition from primary to secondary school?

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3.1 Background

From a movement perspective, a 24-hour day comprises a sequence of time periods spent in movement behaviours that fall on a no/low-high intensity continuum, ranging from sleep to sedentary behaviour and physical activity (Pedišić 2014). While evidence supports how each of these behaviours is associated with child and adolescent health and wellbeing (Carson et al. 2016; Chaput et al. 2016; Poitras et al. 2016), new research suggests potential synergistic health benefits through achieving certain combinations of movement behaviours during a 24-hour period (Wong et al. 2017; Saunders et al. 2016). This has prompted a paradigm shift where an integrated approach focusing on all behaviours across the movement continuum has been adopted in public health research and promotion (Pedišić, Dumuid & Olds 2017; Chaput et al. 2014).

Several countries (such as Canada, New Zealand and Australia) (Australian Government Department of Health 2019; New Zealand Ministry of Health 2017; Tremblay et al. 2016) have recently released national integrated movement guidelines that provide recommendations for physical activity, sedentary behaviour and sleep across a hypothetical 24-hour day. Current international evidence (Walsh et al. 2018; Carson et al. 2017; Roman-Viñas et al. 2016) indicates that less than 20% of school-aged children and adolescents meet the 24-hour integrated movement guidelines, which include: i) the accumulation of at least 60 min of moderate- to vigorous-intensity physical activity (MVPA), ii) no more than 2 h of sedentary recreational screen time, and iii) obtaining uninterrupted sleep of 9-11 h for ages 5-13y and 8-10 h for ages 14-17y. To promote the concept that the "whole day matters" in achieving optimal health and wellbeing, it is vital to understand the time-use composition of 24-hour movement behaviours and identify the ideal settings and time periods for interventions.

Schools are recognised as an important setting for promoting and establishing healthy movement behaviours in children given the large proportion of waking time they spend in

school. The transition from primary to secondary school has attracted particular attention because of its accompanying changes in the physical, social and academic environment (Morton et al. 2016; Marks et al. 2015; De Meester et al. 2014; Hanewald 2013) that may influence children's movement behaviours. A recent systematic review on sedentary behaviour found that both screen-based sedentary behaviour (e.g., television viewing and computer use) and total sedentary time increase substantially across the school transition period (Pearson et al. 2017). However, little is known about the accompanying changes in physical activity and sleep, although studies have shown age-related declines in these behaviours across childhood and adolescence (Farooq et al. 2018; Patte, Qian & Leatherdale 2017). As the duration of a day is finite (i.e., 24 h), a change in time spent in one behaviour will result in an equal and opposite change in at least one other behaviour (Pedišić 2014). Understanding how 24-hour movement behaviours change, individually (i.e., changes within each individual movement behaviour) and collectively (i.e., changes in the combinations or compositions of 24-hour movement behaviours), over the school transition period will help inform the development of intervention strategies for promoting optimal movement behaviour patterns among school children.

The purpose of this study was to systematically identify and review studies reporting changes in time spent in physical activity, sedentary behaviour and sleep, individually and collectively, across the transition from primary to secondary school to promote further understanding of changes in children's 24-hour movement behaviours during this developmental period.

3.2 Methods

The review was registered with PROSPERO (CRD42018095573) and conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Moher et al. 2009).

Six electronic databases (PsycINFO, PubMed, Scopus, SPORTDiscus, Web of Science and China Academic Journal Network Publishing) were searched from January 1990 until 31 May 2019. No language restrictions were applied at the searching stage. The search strategy is provided in Appendix 3.1. A secondary search was performed by screening the reference lists of the included articles. For studies reporting only sedentary behaviour outcomes, this review considered those that had not been included in a previous systematic review (i.e., published from November 2015 onwards) (Pearson et al. 2017). Search records were extracted from the databases and imported into Endnote X7 (Thomson Reuters, San Francisco, USA), where duplicate records were removed. Two independent reviewers (KHC and BK/ZZ) screened titles and abstracts of the remaining records against the eligibility criteria. Full-text articles for studies meeting the criteria in the initial screening (by at least one reviewer) were retrieved and assessed for final inclusion. Any discrepancies were resolved by discussion between the two reviewers, with a third reviewer (AMP, DC or ADO) consulted when necessary.

Studies were eligible for inclusion if they fulfilled the following criteria: 1) longitudinal, observational studies with repeated objective (including device-based measurements) and/or subjective measurements of time/duration spent in physical activity, sedentary behaviour and or/sleep; 2) inclusion of participants in their last two years of primary/elementary school (referred to hereafter as primary school) at baseline (or Time 1) and first two years of secondary/middle/high school (referred to hereafter as secondary school) at follow-up (or Time 2); 3) full-text journal articles or short reports (excluding published abstracts) that were written in English, Chinese, Portuguese, Spanish, Polish or Malay; and 4) published or accepted/in-press in a peer-reviewed journal at the time of review. Intervention studies were considered for inclusion if they had reported results for a control group, or combined control and intervention groups where non-significant intervention effects were observed on the behaviours of interest. For studies that did not clearly report the school grades/levels of the participants, the lead or

corresponding author was contacted for clarification or the protocol paper/relevant publications cited in each study were examined.

Studies were excluded if they were conducted in special populations (e.g., participants with specific health condition) or did not report data for the same participants at all the time points of interest. Reviews, conference proceedings, dissertations and non-scholarly sources were also excluded from the review. Where multiple articles were identified for the same study, those that had no overlap in the reported outcomes of interest were considered for inclusion.

A pre-standardized form was used to extract data from included studies by one reviewer (KHC) and checked by a second reviewer (BJK/ZZ). Extracted information included: bibliographic details (lead author, year of publication, country of study), details of the study sample (size, percentage with complete data, age and/or school grade), the follow-up period (frequency and length), the behaviour domain assessed (e.g., daily MVPA), the method of measurement (objective or subjective), study instrumentation (e.g., accelerometer or self-report questionnaire) and results summary.

Included studies were assessed for risk of bias (ROB) using three adapted items from Cliff et al. (2016): (i) were the participants representative of the target population? (selection bias); (ii) did an adequate percentage of participants (≥70%) have complete data? (attrition bias); and (iii) did the measure of behaviour demonstrate adequate reliability and/or validity in children or adolescents? (detection bias – based on intraclass correlation coefficient ≥0.4 (Cicchetti & Sparrow 1981), Cohen's kappa ≥0.4 (Cicchetti & Sparrow 1981), correlation coefficient ≥0.5 (Hinkle, Wiersma & Jurs 2003) or Area Under the Curve of Receiver Operating Characteristic ≥0.7 (Zweig & Campbell 1993)). For studies that used accelerometry, the validity of cut-point definitions for each behavioural domain was determined by consulting relevant studies and reviews (van Loo et al. 2018; van Loo et al. 2017; Trost et al. 2011) or examining the

supporting evidence cited in each study. These items were independently coded by two reviewers (KHC and BJK) as 'low', 'unclear' or 'high' ROB, and an overall rating of 'low' ROB was applied for studies with at least two out of three items coded as 'low' ROB. Where studies reported more than one type of behaviour (or different domains), the ROB was evaluated for each domain. Discrepancies between the two reviewers were resolved through discussion or consultation with a third reviewer (AMP, DC or ADO). The reviewers (KHC and BJK) reported 86% agreement with independent criterion assessments conducted on the included studies (18 out of 22 items). Studies were not excluded from the review based on ROB assessment.

A narrative synthesis focusing on the significance and direction of change was conducted to evaluate evidence on behavioural changes over the school transition period. The change was categorised as 'increase' or 'decrease' if it was statistically significant (p-value<0.05); otherwise 'no change' (p-value≥0.05). The statistical significance data were extracted from the articles or manually calculated using paired-samples t-test based on the reported mean changes. For articles that did not provide statistical significance data nor mean changes, the descriptive results were presented in this review. Whenever possible, subgroup analyses were performed to examine if the changes were moderated by sex or by types of measures/domains of the behaviour.

3.3 Results

The database searches identified 9,539 articles; 5,977 articles remained after duplicates were removed (Figure 3.1). Following the title and abstract screening, 112 articles were retrieved for full-text review. Of these, six articles (Barr-Anderson et al. 2017; D'Haese et al. 2015; Marks et al. 2015; De Meester et al. 2014; Cooper et al. 2012; Jago, Page & Cooper 2012) met the inclusion criteria and were included in this review.

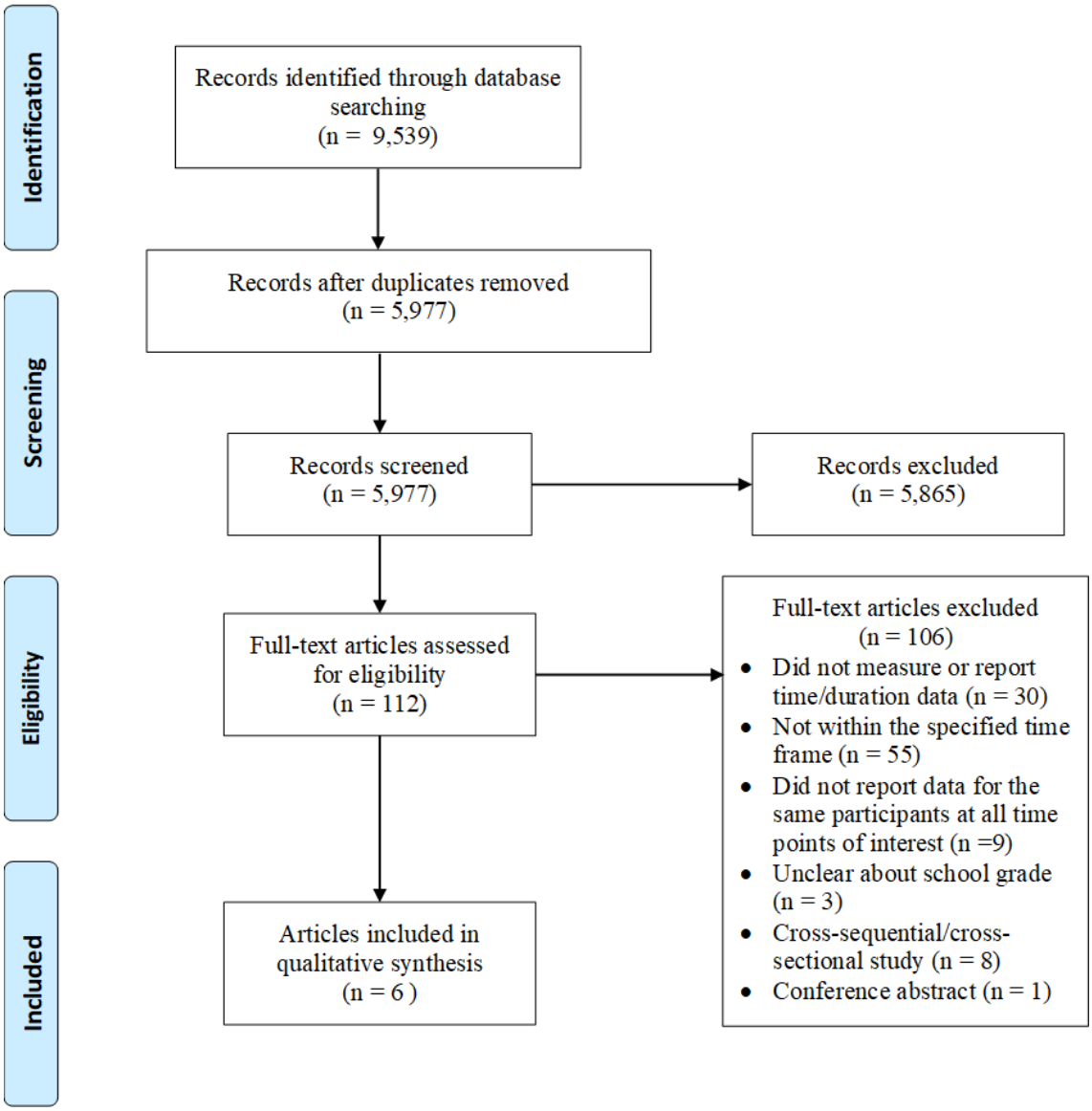

Figure 3.1 Flowchart of study selection process

The six articles analysed data from four studies conducted in the United Kingdom (Cooper et al. 2012; Jago, Page & Cooper 2012), Belgium (D'Haese et al. 2015; De Meester et al. 2014), Australia (Marks et al. 2015) and the United States (Barr-Anderson et al. 2017) (Table 3.1). In all studies, the baseline measurements were conducted during the last year of primary school. The follow-up periods ranged from five months to two years, with measurements conducted during the first and/or second year of secondary school. Five articles (Barr-Anderson et al.

2017; D'Haese et al. 2015; De Meester et al. 2014; Cooper et al. 2012; Jago, Page & Cooper 2012) reported changes in 10 different physical activity outcomes (four accelerometer and six self-report), and one article (Marks et al. 2015) reported changes in both physical activity and sedentary behaviour components including four physical activity outcomes (two accelerometer and two self-report) and five sedentary behaviour outcomes (one accelerometer and four self-report). The analytic samples varied from 127 to 810 participants. Most articles (n=4/6) (Barr-Anderson et al. 2017; Marks et al. 2015; Cooper et al. 2012; Jago, Page & Cooper 2012) had a high ROB as a result of attrition (i.e., 36%-62% of data missing) and selection bias (i.e., inclusion of participants from a specific population segment e.g., urban areas or low socio-economic strata) (see Appendix 3.2). Notably, this review did not identify any studies that examined changes in sleep duration, nor studies that assessed changes in the overall time-use composition of the movement behaviours.

Table 3.1 Characteristics of the included articles

Author & Year; Country	**Age (years)[§]; School grade[§]**		**Length of follow-up (year)**	**Method**	**Outcome *(n)***
	Primary school	**Secondary school**			
Individual behaviour: PA					
Cooper et al. 2012[a] ; United Kingdom	10-11y; 6th grade	7th grade	1	Accel	Weekday MVPA *(469)*
Jago, Page & Cooper 2012[a]; United Kingdom	10-11y; 6th grade	7th grade	1	Accel	After-school MVPA *(810)* Weekend MVPA *(458)*
De Meester et al. 2014[b]; Belgium	M: 11.1y	M: 13.4y	2	Accel	Weekday MVPA *(140)*
				SR	Active transport to and from school *(420)* Extracurricular PA at school *(420)* Total PA *(420)*

D'Haese et al. 2014[b]; Belgium	M: 11.1y	M: 13.4y	2	SR	Walking for transport during leisure time *(321)* Cycling for transport during leisure time *(321)* Sports during leisure time *(321)*
Barr-Anderson et al. 2017; United States	5th grade	6th grade; 7th grade	2[#]	Accel	Total PA *(643)*
Combined behaviours: PA – SB					
Marks et al. 2015 Australia	M: 12.2y; 6th grade	M: 12.8y; 7th grade	5 – 8 months	Accel	Daily MVPA *(127)* Daily LPA *(127)* Daily SED *(127)*
				SR	Being 'very active' after school *(237)* Being 'very active' during weekend *(242)* Weekday leisure ST *(240)* Weekend leisure ST *(239)* Weekday homework ST *(241)* Weekend homework ST *(239)*

[§] where reported; *n*=sample size for paired analysis.
[a,b] References with the same superscript letter analysed data from the same study.
[#] Two annual follow ups at secondary school: One at 6th grade and another at 7th grade.
M=mean; PA=physical activity; MVPA=moderate- to vigorous-intensity PA; LPA=light-intensity PA; SB=sedentary behaviour; SED=sedentary time; ST=screen time; Accel=accelerometer; SR=self-report.

Table 3.2 presents a summary of changes in individual and combined movement behaviour components by time segments across the school transition (see Appendix 3.3 and 3.4 for full results of all included articles). Based on the studies reporting only physical activity (Barr-Anderson et al. 2017; D'Haese et al. 2015; De Meester et al. 2014; Cooper et al. 2012; Jago, Page & Cooper 2012), most outcomes assessed (n=7/10) showed significant changes, with four (one accelerometer and three self-report outcomes) decreasing over the transition period, depending on the time-segment of the day or week. Two studies assessed changes in daily total physical activity. One study reported a significant decrease in total physical activity (self-report) over a two-year period (De Meester et al. 2014). Another reported that total physical activity (accelerometer) decreased with the initial transition to secondary school but remained stable

from the first to second year of secondary school across all ethnic groups and parental education levels (Barr-Anderson et al. 2017); however, it was not possible to determine if the changes were statistically significant as neither p-values nor mean changes were reported.

Table 3.2 Changes in individual and combined movement behaviours (by time segments) across the transition from primary to secondary school

Time segments	Outcome assessed (method)	Direction of change (from primary to secondary school)
Individual behaviour: PA		
Average daily	Total PA (SR) (n=1)[a]	Decrease
	Total PA (Accel) (n=1)[b]	Unknown[#]
Weekdays	MVPA (Accel) (n=2)	Increase
	Active transport to and from school (SR) (n=1)	Increase
In-school	Extracurricular PA (SR) (n=1)[c]	Decrease
After-school	MVPA (Accel) (n=1)	B: Decrease; G: Decrease
Weekend days	MVPA (Accel) (n=1)	B: Increase; G: Increase
Leisure time	Walking for transport (SR) (n=1)	B: Decrease; G: No change
	Cycling for transport (SR) (n=1)	B: No change; G: No change
	Participation in sports (SR) (n=1)	B: Decrease; G: Decrease
Combined behaviours: PA – SB (n=1)		
Average daily	PA: MVPA (Accel)	Decrease
	PA: LPA (Accel)	Decrease
	SB: SED (Accel)	Increase
Weekdays	SB: Leisure ST (SR)	Increase
	SB: Homework ST (SR)	Increase
After-school	PA: Being 'very active' (SR)[d]	Increase
Weekend days	PA: Being 'very active' (SR)[d]	No change
	SB: Leisure ST (SR)	No change
	Homework ST (SR)	Increase

[#] Data on statistical significance and mean changes were not provided.
[a] Defined as the sum of participation in active transport, physical education, extracurricular PA at school and sports during leisure time (De Meester et al. 2014).
[b] Defined as the sum of time spent in LPA and MVPA (Barr-Anderson et al. 2017).
[c] Defined as the sum of participation in PA during playtime, lunch break, after-school hours or at class or school tournaments (De Meester et al. 2014).
[d] Defined as participation in sports, dance or play games in which children were very active (Marks et al. 2015).
n=number of studies that reported the particular outcome; PA=physical activity; MVPA=moderate- to vigorous-intensity PA; LPA=light-intensity PA; SB=sedentary behaviour; SED=sedentary time; ST=screen time; Accel=accelerometer; SR=self-report; B=boys; G=girls.

Two studies assessed changes in physical activity during weekdays; both showed an increase in MVPA (accelerometer) over time (De Meester et al. 2014; Cooper et al. 2012). One study also

reported an increase in MVPA (accelerometer) during weekends but a decrease during the after-school period among boys and girls (Jago, Page & Cooper 2012).

One study reported a decrease in self-report participation in extracurricular physical activity at school (De Meester et al. 2014) and sports during leisure time (for both boys and girls) (D'Haese et al. 2015). This study also showed an increase in active transport to and from school (De Meester et al. 2014), but no change in cycling for transport during leisure time (for both boys and girls) (D'Haese et al. 2015). However, mixed results emerged for walking for transport during leisure time where a decrease in time was observed among boys but no change among girls (D'Haese et al. 2015).

Only one study (Marks et al. 2015) reported changes in two movement behaviours (i.e., physical activity and sedentary behaviour) concurrently during the school transition period. On an average daily basis, light-intensity physical activity (LPA) (accelerometer) and MVPA (accelerometer) significantly decreased while total sedentary time (accelerometer) increased. There was an increase in time spent being 'very active' (self-report) during the after-school period, but no change during weekends. On the other hand, significant increases were observed in screen time measures (self-report) on both weekdays (for leisure only) and weekends.

3.4 Discussion

This study reviewed evidence on individual and collective changes in 24-hour movement behaviours including time spent in physical activity, sedentary behaviour and sleep across the transition from primary to secondary school. Based on the findings of the included studies, there was limited but consistent evidence of a change in physical activity over the school transition period; however, the direction of the change was dependent on the time segments of the day or week. Significant decreases were observed in total daily physical activity and during specific time periods (i.e., in-school, after-school and leisure time). There also appeared to be a

concurrent but opposite change in sedentary behaviour, as suggested by the single study that explored combined behaviours (Marks et al. 2015). This review, however, did not retrieve any studies that examined changes in sleep duration, nor studies that assessed changes in the overall 24-hour movement behaviour time-use composition.

The findings of a decrease in daily physical activity outcomes is consistent with the literature reporting age-related decreases in physical activity levels from childhood into adolescence (Farooq et al. 2018; Corder et al. 2015; Dumith et al. 2011). Interestingly, this review found consistent evidence from two studies for an increase in physical activity outcomes (accelerometer) during weekdays (De Meester et al. 2014; Cooper et al. 2012), but conflicting results for weekends where one study reported an increase (accelerometer) (Jago, Page & Cooper 2012) and another reported no change (self-report) (Marks et al. 2015). However, Brooke et al. (2016) found significant decreases in accelerometer-measured physical activity outcomes (total physical activity and MVPA) on both weekdays and weekends over a 4-year period spanning the transition from childhood to adolescence. The discrepancy could be attributed to differences in the duration of follow-up assessments, which may have reflected behaviours at different developmental stages (i.e., within childhood versus childhood-to-adolescence); or the variation between schools in their approach to providing support for participation in physical activity (e.g., provision of sports or physical activity opportunities during lunch break and after-school period) (De Meester et al. 2014; Marks et al. 2015). However, this may simply indicate that the school transition has a differential impact on children's physical activity, particularly during weekdays.

This review found some evidence to suggest that physical activity decreases not only while in school (De Meester et al. 2014) but also after-school (Jago, Page & Cooper 2012) or during the leisure time period (D'Haese et al. 2015) when children move from primary to secondary school. This is similar to longitudinal observations showing an age-related decrease in physical

activity during both in-school (Brooke et al. 2016) and out-of-school periods (Brooke et al. 2016; Arundell et al. 2013a) across childhood and adolescence. Such decreases may be due to a concurrent increase in sedentary behaviour, as shown in previous research (Arundell et al. 2016; Morton et al. 2016; Marks et al. 2015). Further, literature shows that the after-school period (typically defined as end-of-school to 6pm) (Arundell et al. 2013b) makes a substantial contribution to the accumulation of children's daily physical activity (Arundell et al. 2015; Arundell et al. 2013a), particularly as children enter adolescence (Arundell et al. 2013a). These data suggest that the decrease in physical activity participation during the after-school or leisure time period may be the major contributor to the overall decline in daily physical activity levels during the transition to secondary school, as identified in this review. Further studies are warranted to explore changes in accumulation of physical activity across different time segments (e.g., during/after-school period) and their associations with changes in overall physical activity levels that accompany this school transition.

Only one study in this review reported changes in active transportation over the school transition period, where the time spent in active school travel increased (De Meester et al. 2014) but no change for active travel during leisure time (except among boys where walking for transport decreased) (D'Haese et al. 2015). However, most active travel studies to date have reported a stable trend in participation rate between childhood and adolescence (Kemp et al. 2019). The study by Cooper et al. (2012) found that children's school travel mode was associated with their physical activity across the school transition, whereby a change from passive to active transportation was associated with an increase in total MVPA, and vice versa. Promoting active school travel may therefore be a potentially important and effective approach to offset the decrease in physical activity observed at other times of the day throughout the transition period. Because the distance between home and school appears to be an important determinant of children's travel mode (Cooper et al. 2012), the broader population intervention approaches may need to be complemented by specialised strategies targeted at different

subgroups. For example, strategies seeking to promote walking to school may be best targeted at children who live within a short distance from school, while children who live far away may be encouraged to travel by bike or to be dropped off at a walkable distance from school (Cooper et al. 2012).

No additional studies reporting data on sedentary behaviour were found since the previous systematic review (Pearson et al. 2017). In that review, the authors identified 11 articles (n=9 studies) that assessed changes and/or tracking of sedentary behaviour across the school transition. There was consistent evidence demonstrating an increase in sedentary behaviour over time, with accelerometer-based studies showing an increase of approximately 10-20 min/day per year in total sedentary time. Screen-based sedentary behaviour also tracked moderately (tracking coefficients *r* ranged between 0.3 and 0.5) from primary to secondary school, suggesting the direction and magnitude of the behavioural change is relatively consistent (Pearson et al. 2017). The present review provides further evidence to suggest that an increase in sedentary behaviour may be at least partly attributed to the decrease in physical activity during specific time periods (e.g., after-school and leisure time); although it remains debatable whether there is a direct displacement of time spent among these two behaviours (Pearson et al. 2014). Further research that explores concurrent changes in physical activity and sedentary behaviour across different time segments are required to confirm the inter-relationships between these behaviours.

This review did not identify any studies reporting changes in sleep duration during the school transition period. Several longitudinal studies have reported a gradual decrease in sleep duration as children enter adolescence (Crowley et al., 2014; Laberge et al., 2001), a period which frequently coincides with the transition to secondary school. A recent multi-country study also reported the existence of temporal and bi-directional associations between nocturnal sleep duration with physical activity and sedentary time among children aged 9-11y (Lin et al. 2018).

Specifically, an increase in sedentary time and a decrease in MVPA were associated with a decrease in sleep duration during the subsequent night, although the observed effect sizes were small and the associations varied between the sexes and countries (Lin et al. 2018). These results, together with the findings of the current review on changes in physical activity and sedentary behaviour, suggest that a concurrent change in sleep duration across the primary to secondary school transition is possible.

The largest knowledge gap identified in this review is the absence of research investigating the overall 24-hour movement behaviour composition. The challenge of measuring the full movement spectrum in free-living conditions and the lack of standardised classification criteria for different behaviours may be the reason for the lack of evidence in this field (Kuzik et al. 2017; Pedišić, Dumuid & Olds 2017). However, with recent advances in wearable accelerometry-based technology (e.g., wrist-worn, waterproof devices) (Troiano et al. 2014) and data processing and analysis methods (Migueles et al. 2019; Dumuid et al. 2018; Migueles et al. 2017), more studies are now collecting behavioural data using a 24-hour accelerometry protocol. This protocol has demonstrated high levels of compliance in children and adolescents (Duncan et al. 2018; Rowlands et al. 2018; Tudor-Locke et al. 2015), and thus, producing more reliable estimates of intensity-specific behaviours. Nevertheless, the accelerometry measures do not provide contextual information of the behaviours, which may be useful in identifying more specific behaviours to prioritise in intervention and public policy. To address the gap, future research is recommended to use both objective/device-based and self-report tools to provide a greater depth of understanding of children's 24-hour movement behaviours. Additionally, it would be worthwhile to characterise changes in time allocations between different movement behaviours during the school transition period, which could have distinct influences on health and wellbeing (García-Hermoso et al. 2018; Grgic et al. 2018).

There is considerable uncertainty about the exact influence of the school transition on children's movement behaviours. A recent longitudinal study in the United States found that there were significant but non-linear declines in children's physical activity during school hours (Lau et al. 2017) over a three-year period, where declines were greater during the transition from primary to secondary school compared to the first two years of secondary school; indicating that the school transition period may have immediate impacts on children's behaviours. This may be due, in part, to the differences in primary and secondary school environmental characteristics (e.g., policies, programmes and facilities for physical activity), which have been shown to be associated with changes in physical activity and sedentary time over this transition period (Morton et al. 2016; De Meester et al. 2014). Another study comparing children's activity patterns between two different school transition systems in Australia (i.e., transitioning to a new secondary school vs. remaining in the same school) also found that changes in children's activity patterns may be moderated by the level of disruption in school environment, where a complete change of school during this transition period was associated with a greater change in the types of activity behaviours (e.g., participation in active school travel and leisure screen time) (Marks et al. 2015). While these findings seem to confirm the influence of a change in school environment on children's movement behaviours, recent research highlights the importance of considering multiple levels of influence (e.g., individual, social, community) and their cross-level interaction effects to understand the change in these behaviours during the school transition (Colabianchi et al. 2019; Pate et al. 2019). For example, having both parental support and a supportive neighbourhood environment may assist in addressing the decrease in children's total physical activity levels as they transition to secondary school (Colabianchi et al. 2019). Further studies are required to examine which of the previously identified factors or determinants (Pedišić, Dumuid & Olds 2017) are associated with the change in overall 24-hour movement behaviour composition to inform the development of effective interventions.

This study extended the scope of previous work by Pearson et al. (2017) with an aim to provide a detailed and systematic understanding of how children's time-use in 24-hour movement behaviours (physical activity, sedentary behaviour and sleep) may change during the transition from primary to secondary school. This approach aligns with the Framework for Viable Integrative Research in Time-Use Epidemiology (VIRTUE) framework (Pedišić, Dumuid & Olds 2017), which acknowledges the importance of adopting an integrated approach when studying movement-related time-use patterns in populations. This review also employed more stringent inclusion criteria using studies that reported data for the same participants within a 4-year period covering the pre-, during, and post-school transition phases, enabling a more nuanced understanding of the intra-individual behavioural changes that occur over this school transition period.

The results of this review should be interpreted with some caution given the paucity of studies identified. Most articles in this review had a high ROB (n=4/6), although the findings were relatively consistent across all studies. It was not feasible to conduct a meta-analysis for quantifying behavioural changes due to considerable heterogeneity between studies (e.g., variation in behaviour domains assessed and measurement methodology). While most studies used measures that appeared to be valid, the findings may not be directly comparable due to discrepancies in the definitions of the measures or some methodological decisions, such as the accelerometer data inclusion criteria and cut-points employed for defining intensities of behaviours. It is also important to note that the cut-point-derived activity estimates are prone to bias because the cut-points are typically developed from calibration studies that involved a small and non-representative sample (Pedišić & Bauman 2015). Finally, all studies were conducted in high-income developed countries; thus, the findings may not be generalizable to the populations of low or middle-income countries.

3.5 Conclusion

Despite a limited number of studies, the present review found some important evidence describing the changes in children's 24-hour movement behaviours across the transition from primary to secondary school. Findings from the included studies in this review suggest that changes in physical activity are largely dependent on the time segments of the day or week, indicating the need for targeted period-specific intervention strategies. Specifically, the after-school or leisure time period was identified as a potential target for delivering interventions to prevent a decrease in physical activity and increase in sedentary behaviour across the school transition. On the other hand, there appeared to be a concurrent but opposite change in sedentary behaviour; with existing evidence indicating a substantial increase in both individual sedentary behaviour and total sedentary time over the transition from primary to secondary school (Pearson et al. 2017). No studies investigated changes in sleep duration, or collective changes in all three movement behaviours during a 24-hour period. Additional high-quality studies using an integrated approach are required to explore the changes in children's 24-hour movement behaviour composition and associated factors that accompany the school transition. Such information would facilitate the development of effective interventions by identifying and prioritising the 'at-risk' behaviour(s) to be addressed during this critical developmental period, and subsequently promote the importance of practising an optimal 24-hour movement behaviour pattern for overall health and wellbeing in children and adolescents.

3.6 References

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Chapter 4: Methodology

Chapter 3 presented a systematic review of the literature on changes in time spent in physical activity, sedentary behaviour and sleep during the transition from primary to secondary school. The review confirmed that no known previous research has investigated changes in the 24-hour composition of all three movement behaviours across the school transition period. Furthermore, as discussed in Chapter 2, there remains gaps in the current evidence base regarding the collective and relative associations between 24-hour movement behaviours and psychosocial health in children. This justifies the aim and research questions for this thesis, which have been explored in three original research studies. This chapter provides a brief overview of the data sources and analytical approach used in these three studies.

4.1 Data sources

The first and third studies of this thesis (Chapters 5 and 7) analysed primary data from a longitudinal school-based survey (hereafter referred to as Survey 1), while the second study (Chapter 6) used secondary data from a national longitudinal survey (hereafter referred to as Survey 2). The following sections briefly describes the methodology used in each survey and the primary variables examined in this thesis.

4.2 Survey 1

4.2.1 Study design and sampling

This was a one-year prospective longitudinal survey that followed a cohort of children from their final year of primary school (Year-6; aged 10-12y) to their first year of secondary school (Year-7; aged 11-13y). Participating children were recruited from a convenience sample of Government and Independent schools (three government primary schools, three government central schools, six independent schools) located within a 400 km radius of the city of Wollongong in New South Wales, Australia. These schools were chosen to provide a study

sample that reflects two modes of school transition in Australia. The first transition involved children moving to a new school for secondary education (recruited from government primary schools), whereas the second transition involved children attending the same school for both primary and secondary education (recruited from government central schools and independent schools).

This study was approved by the Human Research Ethics Committee of the University of Wollongong (HREC 2017/255) (Appendix 4.1) and additional approval was received from the New South Wales Department of Education (SERAP No. 2018365) for the Government schools. (Appendix 4.2). In all instances, written consent was obtained from the school principals (Appendix 4.3) prior to the commencement of the study.

4.2.2 Participants

Written parental (or legal guardian) consent was required for this study as it involved children under 16 years of age. An information sheet and consent form (Appendix 4.4) were sent home to all Year-6 children at the consenting schools to seek parental (or legal guardian) permission for their participation in this study at baseline. An information sheet about the study protocol was also provided to the children (Appendix 4.5). Only children who provided written parental consent and verbal assent were recruited into the study. At follow-up time points, a passive consent form (Appendix 4.6) was delivered to the parents (or legal guardians) at their residential address or through email (depending on their preference indicated on the initial consent form) to seek their permission for the child to continue participating in the study. For children who had moved to a new school during the study period, a new active consent was required from their parents (or legal guardians) and the school principal from the new school for them to continue participating in the follow-up assessment(s).

4.2.3 Sample size

Two calculations were performed to determine the sample size required to adequately address the two major research questions explored in this thesis (see Table 4.1 for the details of the calculations). These calculations indicated that a sample size of 413 participants would be sufficient to answer both research questions.

Table 4.1 Sample size calculations

Chapter	Sample size calculation
5	**Research Question 1: How does the distribution of time spent in different intensities and domains of 24-hour movement behaviours change across the transition from primary to secondary school?** To answer this research question would require a range of 19 to 180 participants to detect a mean change of 16 min/day (standard deviation (SD)=76) in sedentary time, 23 min/day (SD=33) of light-intensity physical activity (LPA), and 4 min/day (SD=13) of moderate- to vigorous-intensity physical activity (MVPA) over the primary to school transition period with a significance level of 0.05 and power of 0.8, based on a previous Australian study (Marks et al. 2015). After adjusting for a design effect of 1.19 (based on an intra-cluster correlation coefficient of 0.01 and an estimated cluster size of 20 students in each school) and considering a possible attrition rate of 20% (due to loss to follow-up and non-compliance with the 24-hour accelerometer wear protocol), the sample size was estimated to range from 27 to 257 participants. Therefore, a sample size of 257 participants would be deemed sufficient.
7	**Research Question 2: Are 24-hour movement behaviours associated with children's psychosocial health during the transition from primary to secondary school?** It was previously reported that the association between the 24-hour movement behaviour composition and psychosocial health outcomes among children and adolescents was weak (R^2=0.06) (Carson et al. 2016). To detect a small effect size (Cohen's f^2 of 0.06) with a significance level of 0.05 and power of 0.8, and with a maximum of 11 predictors included in the model, it was calculated that the survey would require 289 participants with complete data. After adjusting for a design effect of 1.19 (based on an intra-cluster correlation coefficient of 0.01 and an estimated cluster size of 20 students in each school) and considering a possible attrition rate of 20% (due to loss to follow-up and non-compliance with the 24-hour accelerometer wear protocol), the sample size was estimated to be 413 participants.

4.2.4 Data collection

Baseline data were collected between April 2018 and August 2019, with follow-up data collected an average of six months (Follow-up 1: October 2018-March 2020) and 12 months

(Follow-up 2: April 2019-November 2019) after baseline using a standardised data collection protocol. This included anthropometric measurements, self-administered questionnaires (Appendix 4.7) and accelerometer measurements for seven consecutive days. This study was terminated in April 2020 as the University of Wollongong officially suspended all face-to-face data collection due to COVID-19. This resulted in the loss of 22% of data (30 participants) for the second follow-up time point.

4.2.5 Study variables

This section provides a brief description of the primary variables examined in the first (Chapter 5) and/or third study (Chapter 7) of this thesis. These included accelerometer-measured 24-hour movement behaviours, psychosocial health, and participation in specific types of sedentary activities and physical activity.

i. Accelerometer-measured 24-hour movement behaviours

Time spent in 24-hour movement behaviours (sleep, sedentary time, LPA and MVPA) was measured using a GENEActiv accelerometer (ActivInsights Ltd., Cambridgeshire, UK). GENEActiv is a small (36cm x 30cm x 12cm), lightweight (16g) device with an unobtrusive wrist-worn and waterproof design that is ideal for measuring free-living movement behaviours over multiple days (see Appendix 4.8 for an image of the device). This accelerometer has been demonstrated to produce valid and/or reliable estimates of sleep (Antczak et al. 2021), sedentary behaviour (Hurter et al. 2018; van Loo et al. 2017) and physical activity (van Loo et al. 2018) in children. In this study, the accelerometers were set to collect acceleration data at a sampling rate of 75 Hz. Participants were asked to wear the accelerometer on their non-dominant wrist for seven consecutive days. However, data from the first day (i.e., the day the accelerometers were given to the participants) was excluded from this study because data were only collected for a portion of a 24-hour day (defined as midnight-to-midnight period in this study). This resulted in

a maximum of six days of 24-hour recording for the analyses. The accelerometer data processing and analysis criteria are described in detail in Chapters 5 and 7.

ii. Psychosocial health

Psychosocial health was assessed using the self-report version of the Strengths and Difficulties Questionnaires (SDQ) (Goodman 1997) and the Kessler Psychological Distress Scale (K-10) (Kessler et al. 2012). These questionnaires are widely used as psychological assessment tools in Australian national population surveys (Hafekost et al. 2016; Sanson et al. 2005) and have demonstrated adequate psychometric properties for use in children and adolescents (Smout 2019; Van Roy, Veenstra & Clench-Aas 2008; Muris, Meesters & van den Berg 2003). Further information about the questionnaires, including the number of items used and the scoring methods, is reported in detail in Chapter 7.

iii. Self-reported assessment of sedentary behaviour

Participants were asked to report the duration of time spent engaged in a range of sedentary activities on each weekday (during out-of-school hours only; 13 activity items) and weekend day (14 activity items) during a typical school week. These activity items were adapted from the revised version of the Adolescent Sedentary Activity Questionnaire (ASAQ) (Hardy et al. 2016); with an additional item assessing the use of screen devices for social purposes (e.g., using social networking sites) to reflect current trends in children's screen media use. Minor wording changes were made to several original activity items to reflect the current technology environment (see Appendix 4.9 for a comparison of the original and adapted versions of ASAQ). The activity items were further categorised into five domains: recreational screen use, out-of-school educational activities, social activities, passive travel and cultural activities) (Hardy et al. 2016).

iv. Self-reported assessment of physical activity

Participants were asked to indicate their participation (Yes/No) in five specific mode/setting combinations of physical activity over the last three months: competitive team sports inside and outside school, competitive individual sports inside and outside school, and organised but non-competitive physical activity. These activity items were adapted from a longitudinal survey in Australia which investigated changes in physical activity participation among adolescents at two key transition points, including the transition from primary to secondary school (Eime et al. 2016). The original survey question was modified slightly for use in this study by changing the reference period from 12 months to three months to fit the study's time frame and by removing two of the original activity items: physical education classes in school and non-organised physical activity. This was because physical education classes are a mandatory component in New South Wales's school curriculum and students are required to participate in the same number of hours of physical education. As such this amount of time would not vary among participants. There is also a lack of clarity in the definition of what constitutes participation in non-organised physical activity, and in how accurately such activities can be reported (see Appendix 4.10 for a comparison of the original and adapted versions used in this study).

4.3 Survey 2

4.3.1 Study design and sampling

The Longitudinal Study of Australian Children (LSAC) was the first nationally representative longitudinal study of child development in Australia (Australian Institute of Family Studies 2018). Using a cross-sequential design, LSAC follows two cohorts of children recruited in 2004 when they were aged 0-1y (B-cohort; 5107 children) and 4-5y (K-cohort; 4983 children), respectively (Australian Institute of Family Studies 2018). This study employed a two-stage clustered sampling strategy, which involved the random selection of postcodes and then children within these postcodes through the Australia's healthcare database (Medicare) (Soloff, Lawrence & Johnstone 2005).

Data on a variety of topics, including health behaviours and social and emotional outcomes, are collected from participating children and their parents and teachers every two years since 2004 (Australian Institute of Family Studies 2018). Of interest is the time-use diary data, which provides information about how children spend their time in different activities over a 24-hour day (Corey et al. 2014). The use of LSAC data is appropriate and relevant to this thesis because of its longitudinal design permitting the exploration of intra-individual changes in children's time-use behaviours and psychosocial health over time. Specifically, the use of time-use diary data enables the identification of the daily activity domain(s) in which changes are most likely to occur during the primary to secondary school transition period, complementing the analysis of accelerometer-based movement behaviour data collected in Survey 1.

The LSAC study received ethical approval from the Australian Institute of Family Studies Ethics Committee, which is a Human Research Ethics Committee registered with the National Health and Medical Research Council. Informed consent was obtained from all participants. Access to LSAC data for use in this thesis was granted by the National Centre for Longitudinal Data (Appendix 4.11).

4.3.2 Participants

This thesis used data collected from the LSAC K-cohort during Wave 4 (2010) and Wave 5 (2012) when children were aged 10-11y and 12-13y, respectively. These waves were chosen as the follow-up period coincides with the transition from primary to secondary school in Australia. To answer the research questions of this thesis, only data from participants who were still in primary school at Wave 4 and had moved to secondary school at Wave 5 were included in the analysis.

4.3.3 Study variables

This section provides a brief description of the primary variables examined in the second study (Chapter 6) of this thesis. These include the 24-hour domain-specific movement behaviours and psychosocial health.

i. 24-hour domain-specific movement behaviours

Participants were asked to record all activities they engaged in over a 24-hour period in a paper diary on the day prior to their scheduled home interview (Corey et al. 2014). The interviewers then transposed the recorded activities based on a predetermined coding framework (Corey et al. 2014). Additional information about the contexts of the activities was also collected during the interview, including who they were with, where they were, and whether they were outside. The time-use diaries data were collected for only a single day during each data collection wave. The original time-use diary activities were aggregated into eight distinct activity domains for analysis in this thesis: Self-care/Domestic, Physical Activity, Social, Education, Recreational Screen Use, Quiet Time, Sleep and Passive Transport. The operationalisation of the activity domains was determined by consulting previous time-use diary research (Kemp et al. 2020; Olds, Maher & Dumuid 2019). The full list of time-use diary activities is provided as an appendix to Chapter 6 (Appendix 6.2).

ii. Psychosocial health

Among other study instruments, data collected using the self-report version of the SDQ (Goodman 1997) were used as the indicators of children's psychosocial health in the second study of this thesis (Chapter 6). This instrument was also used in the third study (Chapter 7), allowing a comparison to be synthesised from the two studies in this thesis.

4.4 Statistical analysis

A compositional data analysis (CoDA) approach was adopted to answer the research questions of this thesis. CoDA is a novel statistical approach developed for use in the analysis of compositional data, which are subject to a constant-sum constraint (i.e., closed data) and convey only relative, rather than absolute, information (Aitchison 1982).

An example of compositional data is the daily time-use in movement behaviours (sleep, sedentary behaviour and physical activity), which are mutually exclusive (i.e., one can only engage in one of these behaviours at a time) and exhaustive components of a 24-hour day (Pedišić, Dumuid & Olds 2017; Chastin et al. 2015). This means that the movement behaviour data are only meaningful if they are analysed and interpreted as a set of co-dependent variables on a relative scale. This can be done using the CoDA analysis, which involves expressing the movement behaviour data as a set of log-ratios (i.e., the logs of the ratios between behaviours) using a log-ratio transformation (Aitchison 1982). This transfers the data from the constrained simplex space to the unconstrained real space, allowing them to be analysed using the traditional multivariate statistical models (Mateu-Figueras, Pawlowsky-Glahn & Egozcue 2011). It also enables the inclusion of all movement behaviours into the same statistical model without the singularity problems as the log-ratios are not perfectly multi-collinear and contain all the relative information about the movement behaviour composition (Dumuid et al. 2018; Chastin et al. 2015). More importantly, CoDA offers the ability to analyse and interpret the associations of daily movement behaviours with health outcomes using an integrated approach, where the results could be interpreted in relation to either the overall movement behaviour composition, the reallocations of time between behaviours, or the changes in one behaviour relative to the remaining behaviours within the composition (Dumuid et al. 2020; Pedišić, Dumuid & Olds 2017).

Table 4.2 summarises the statistical analyses performed using the CoDA approach in each of the study chapters (Chapters 5 to 7). A more detailed description of the analyses can be found in the respective study chapters.

Table 4.2 List of CoDA-based statistical analyses performed in this thesis

Chapter	Study	Statistical analyses
5	Changes in 24-hour movement behaviours during the transition from primary to secondary school among Australian children	Multivariate analysis of variance (MANOVA) for repeated measures
6	Changes in 24-hour domain-specific movement behaviours and their associations with children's psychosocial health during the transition from primary to secondary school: a compositional data analysis	MANOVA for repeated measures, multiple linear regression models and compositional isotemporal substitution models
7	Cross-sectional and longitudinal associations between 24-hour movement behaviours, recreational screen use and psychosocial health outcomes in children: a compositional data analysis approach	Linear mixed models

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Chapter 5: Changes in 24-hour movement behaviours during the transition from primary to secondary school among Australian children

Chapter 4 provided an overview of the data sources for the three original research studies conducted as part of this thesis. This chapter reports the first of the three original research studies. The rationale and design of this study were informed by the findings from the systematic review presented in Chapter 3, which showed a lack of research on changes in the full 24-hour movement behaviour time-use composition during the transition from primary to secondary school. This chapter seeks to address this knowledge gap by investigating the following research questions:

Research Question 1:

How does the distribution of time spent in different intensities and domains of 24-hour movement behaviours change across the transition from primary to secondary school?

Sub-research questions:

1.1 Does the change in 24-hour movement behaviour composition differ by day type (weekdays and weekend days)?

1.2 Is the change in 24-hour movement behaviour composition moderated by the child's socio-demographic (sex, socio-economic status) and health characteristics (body weight status and pubertal development)?

1.4 How does adherence to the Australian 24-Hour Movement Guidelines for Children and Young People (aged 5-17y) change during the school transition period?

This chapter has been published as:

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5.1 Background

Sleep, sedentary behaviour and physical activity are collectively referred to as '24-hour movement behaviours' because they reflect the full range of movement intensity continuum over a 24-hour period (Tremblay et al. 2016). Recognising the interactions and health implications of the combinations of these three behaviours (Carson et al. 2016; Saunders et al. 2016), several countries, including Australia, have released national 24-hour integrated movement guidelines for school-aged children and adolescents (Australian Government Department of Health 2019; New Zealand Ministry of Health 2017; Tremblay et al. 2016). These guidelines provide specific recommendations for time spent in sleep (9-11 h for ages 5-13y and 8-10 h for ages 14-17y), sedentary recreational screen time (≤2 h) and moderate- to vigorous-intensity physical activity (MVPA) (≥60 min) for a healthy 24-hour day. Studies have shown that only a small proportion of children (4.8%-10.8%) and adolescents (1.6%-9.7%) meet all three movement behaviour recommendations, despite evidence of their favourable associations with health (e.g., lower adiposity, better mental health) (Rollo, Antsygina & Tremblay 2020). Because movement behaviours established during childhood and adolescence may track into adulthood (Hayes et al. 2019), it is crucial to understand how these behaviours develop and change concurrently over time and to identify the key behavioural settings for interventions.

The transition from primary (ages ~5-12y) to secondary school (ages ~12-17y) has been highlighted a key period during which behavioural changes may occur due to its accompanying changes in the physical, social and/or academic environments (Morton et al. 2016; Marks et al. 2015; Hanewald 2013). There is some evidence to suggest that sedentary behaviour increases (Pearson et al. 2017), while physical activity declines during this transition period (Chong et al. 2020). However, no known study has investigated changes in the full 24-hour movement behaviour time-use composition (including sleep) (Chong et al. 2020). Due to the compositional nature of time-use data, the time spent in 24-hour movement behaviours is intrinsically collinear

(i.e., changing time spent in one behaviour requires compensatory changes in at least one other behaviour) and should not be analysed in isolation from each other (Pedišić, Dumuid & Olds 2017). A novel compositional data analysis approach (CoDA) has been recommended for the analysis of movement behaviour data (Dumuid et al. 2018; Chastin et al. 2015). Specifically, CoDA overcomes the limitations of traditional statistical approaches by considering the closed nature of time-use data and the co-dependency of movement behaviours (Dumuid et al. 2018; Chastin et al. 2015). This allows concurrent changes in time allocations between different behaviours over a 24-hour period to be assessed, providing an indication of which behaviours contribute to a change in the overall movement behaviour composition and should perhaps be targeted for interventions during this transition period. Further, no known studies have examined the changes in adherence to the new 24-hour integrated movement guidelines during the school transition.

In addition to quantifying changes in overall time-use composition, it is important to understand the characteristics of behavioural changes for effective intervention development. Specifically, identifying the segments of the day/week and behavioural domains/contexts in which changes are most likely to occur may guide the selection of promising intervention targets (Brooke et al. 2016). This is particularly relevant for primary to secondary school transition studies, as changes in physical activity over this period appear to be time-specific (e.g., decreased physical activity participation during after-school period) and domain-specific (e.g., increased active school travel but decreased participation in sports) (Chong et al. 2020; Remmers et al. 2020; Eime et al. 2016).

This study aimed to describe changes in 24-hour movement behaviour composition (i.e., time spent in sleep, sedentary time, light-intensity physical activity (LPA), MVPA) during the transition from primary to secondary school. Specifically, this study examined changes in daily movement behaviour composition and specific behavioural domains/contexts, and the resulting

changes in meeting the 24-hour integrated movement guidelines. As children's movement behaviour patterns are likely to vary between weekdays and weekends (Evans-Whipp & Gasser 2019; Brooke et al. 2014), the magnitude of behavioural changes was further evaluated and compared between the two types of days. This study also investigated whether the change in daily movement behaviour composition is moderated by the child's sex, socio-economic status, body weight status or pubertal development, given their previously reported associations with at least one movement behaviour (Evans-Whipp & Gasser 2019; Hardy et al. 2016; Sadeh et al. 2009). This knowledge would help to determine if interventions need to be targeted for particular subgroups within the population.

5.2 Methods

5.2.1 Study design and participants

This longitudinal study followed a cohort of children in their last year of primary school (Year-6; aged 10-12y) through to the first year of secondary school (Year-7; aged 11-13y). Participating children were recruited from a convenience sample of government and independent schools that were located within a 400 kilometres radius of the city of Wollongong in Australia. Based on the lists of registered schools in 2017 (provided by the relevant state education authorities), 73 schools were invited to take part in the study between July 2017 and December 2018. These schools were selected to provide a study sample reflecting two modes of transition common in Australia. The first transition involved children moving to a new school for secondary education (recruited from government primary schools); while the second transition involved children attending the same school for both primary and secondary education (recruited from government central schools and independent schools). In general, Australian children spend approximately 6 h/day at schools during the primary school period and 6.5 h/day during the secondary school period.

All Year-6 children at the consenting schools were invited to participate; only those providing written parental consent and verbal assent were recruited into the study. At follow-up time points, parental consent was obtained via two methods: 1) passive consent for children who had stayed at the same school; or 2) new active consent for children who had moved to a new school. Approval was also obtained from the schools that children had transitioned to before data collection commenced. Baseline data were collected between April 2018 and August 2019, with follow-ups taking place an average of six months (range 4-9 months) (Follow-up 1: October 2018-March 2020) and 12 months (range 11-16 months) (Follow-up 2: April 2019-November 2019) after baseline. The variation in baseline time frames between schools resulted in different combinations of follow-up data points across the two schooling stages; some participants had one follow-up data point in primary school and one in secondary school, while others had both follow-up data points in secondary school. For this study, the analytical sample included participants who had provided valid accelerometry data at baseline (representing primary school period; referred to hereafter as T1) and one time point during the secondary school period (referred to hereafter as T2). Where two valid data points were available for T2, the one with the longest follow-up time was chosen for analysis to reflect a more persistent (rather than transient) impact of transition on movement behaviours.

This study was approved by the Human Research Ethics Committee of the University of Wollongong (HREC 2017/255). Permission to conduct the study in the Government schools was received from the New South Wales Department of Education (SERAP No. 2018365).

5.2.2 Measures

i. Accelerometer-measured 24-hour movement behaviours

Time spent in sleep, sedentary, LPA and MVPA was assessed continuously for six days (24 h/day) using a GENEActiv accelerometer (ActivInsights Ltd., Cambridgeshire, UK) placed on the non-dominant wrist. The raw accelerometry data (sampled at 75 Hz) were downloaded and

saved in binary format using GENEActiv PC software v3.2 (ActivInsights Ltd., Cambridgeshire, UK). The data files were processed in R using the GGIR package (v1.10-7) (Migueles et al. 2019). The acceleration signals were auto-calibrated using local gravity as a reference (van Hees et al. 2014) and converted into gravity-corrected vector magnitude units (Euclidean norm minus one, ENMO) (van Hees et al. 2013). The average ENMO values were calculated over 5-second epochs and expressed in milli-gravitational units (m*g*).

Accelerometer non-wear time was estimated based on the standard deviation (SD) and value range of each accelerometer axis, calculated over 60-min windows with 15-min increments (van Hees et al. 2013). A time window was classified as non-wear if, for at least two out of the three axes, the SD was less than 13 m*g* or the value range was less than 50 m*g*. For each 15-min period detected as non-wear time during the valid wearing days, missing data were imputed using the mean values calculated from valid data at the same time on other recorded days. Sleep duration was calculated as the difference between sleep onset and sleep offset timings detected using van Hees et al.'s algorithm (2018), which has been applied previously in wrist-worn accelerometry studies involving children (Antczak et al. 2021; Fairclough et al. 2017). Sleep efficiency was calculated as the percentage of min scored as sleep between sleep onset and sleep offset. The amount of time spent sedentary (ENMO <52 m*g*), LPA (ENMO 52-191 m*g*) and MVPA (ENMO ≥192 m*g*) were estimated using age-appropriate ENMO cut-points (Hurter et al. 2018; Hildebrand et al. 2014).

For data inclusion, the accelerometer wear time criteria was at least 16 h/day for at least three days (including one weekend day) (Fairclough et al. 2017). Any wearing day(s) with ≤200 min of sleep and ≥1000 min of sedentary time were considered invalid (Dumuid et al. 2019) and excluded from the analysis. Average time spent in each movement behaviour and sleep characteristics (sleep timings and efficiency) were calculated separately for weekdays and

weekends, and the average daily estimates were computed as ([average of weekdays*5]+[average of weekends*2])/7.

ii. Self-reported assessment of sedentary behaviour and physical activity

Participants were asked to report the amount of time spent doing sedentary (i.e., while sitting) activities for each weekday (outside of school hours only; 13 activity items) and each weekend day (14 activity items) during a typical school week. These activities were adapted from the revised version of Adolescent Sedentary Activity Questionnaire (Hardy et al. 2016); with an additional item included to assess the use of any screen devices for social purposes to reflect current trends in children's use of screen media. Minor wording changes were made to several original activity items to fit the current technology environment. For analysis purposes, the activity items were categorised into five domains: recreational screen time, out-of-school educational activities, social activities, passive travel, and cultural activities (Hardy et al. 2016). Raw data were summarised into an average duration for each domain by weekdays and weekends, and the average daily duration was calculated as ([average of weekdays*5]+[average of weekends*2])/7.

Participants were also asked to indicate their participation in five specific mode/setting combinations of physical activity (Yes/No) during the current school term: competitive team sports inside and outside school, competitive individual sports inside and outside school, and organised but non-competitive physical activity (adapted from Eime et al. 2016).

iii. Adherence to 24-Hour Movement Guidelines

Participants were categorised as meeting the specific individual movement guideline if they met the recommendations for 1) MVPA (≥60 min/day), 2) sedentary recreational screen time (≤2 h/day), or 3) sleep (9-11 h/night) (Australian Government Department of Health 2019). The

proportions of participants meeting/not meeting the individual and integrated (all three behaviours) guidelines were calculated and separately for weekdays and weekends.

iv. Other measures

Socio-demographic information (child's sex, date of birth and home postcode) were provided by parents/legal guardians on the consent form. Using the home postcode provided, neighbourhood socio-economic position was determined according to the 2016 Socio-Economic Indexes for Areas Index of Relative Socio-Economic Disadvantage (SEIFA IRSD) (Australian Bureau of Statistics 2018) and used as an indicator of socio-economic status. Body weight was measured using a digital scale (Model 874; SECA, Hamburg, Germany), and height was measured using a stadiometer (Model 217; SECA, Hamburg, Germany). Body mass index z-scores (BAZ) were calculated using AnthroPlus version 1.0.4 (World Health Organization, Geneva, Switzerland) and categorised as thinness/normal weight or overweight/obese based on the 2007 World Health Organization growth reference (de Onis et al. 2007). Pubertal development was assessed using self-reported Pubertal Developmental Scale (Carskadon & Acebo 1993). Participants were asked to describe their development status on three general (i.e., growth spurt in height, body hair growth, skin change) and two sex-specific (boys: facial hair growth and voice change; girls: breast development and the onset of menarche) indicators of puberty on a 4-point scale: 1='has not yet started' (or 'no' for menarche item), 2='has barely started', 3='has definitely started' and 4='seems completed' (or 'yes' for menarche item), A pubertal progression score (range 1-4) was computed by averaging the scores of all five items; and a change score was calculated (T2 minus T1) and used in the moderator analysis.

5.2.3 Statistical analyses

Statistical analyses were performed in IBM SPSS Statistics for Windows (version 26; IBM Corp., Armonk, New York), and R software (version 3.6.2; R Foundation for Statistical

Computing, Vienna, Austria) using the 'compositions' (version 2.0.0) (van den Boogaart & Tolosana-Delgado 2008), 'car' (version 3.0-10) (Fox & Weisberg 2019) and 'boot' (version 1.3-25) (Canty & Ripley 2020; Davison & Hinkley 1997) packages. Descriptive statistics were calculated using mean and standard deviation for continuous variables, and frequency and percentage for categorical variables. Differences in descriptive characteristics between the analytical and excluded samples were examined using independent t-tests or Chi-Square tests. Changes in characteristics of the analytical sample from T1 to T2 were tested using paired sample t-tests or McNemar tests.

The analysis of 24-hour movement behaviours (i.e., accelerometer measures of sleep, sedentary time, LPA and MVPA) followed a CoDA analytical approach, as detailed in previous studies (Dumuid et al. 2018; Chastin et al. 2015). Time spent in each behaviour was described using both standard (arithmetic mean and standard deviation) and compositional (compositional mean and variation matrix) descriptive statistics. The four-part movement behaviour composition was expressed as a set of three isometric log-ratio coordinates (*ilrs*) for statistical analyses. Repeated measures multivariate analysis of variance (MANOVA) was used to assess if the overall movement behaviour composition changed from T1 and T2; where the interactions between time points (T1 and T2) and the set of *ilrs* (representing movement behaviour composition) were tested. This does not indicate which behaviours are driving the change in the composition. To further explore this, the log-ratio difference of compositional means between the time points (*ln*[T2/T1]) and its 95% bootstrap confidence interval for each behaviour were derived and plotted for interpretation (Martín-Fernández, Daunis-i-Estadella & Mateu-Figueras 2015). A particular behaviour is considered to have increased from T1 to T2 if the data point of the log-ratio difference falls above the zero Y-axis reference line; or decreased from T1 to T2 if it falls below the zero line. The change in that behaviour is considered significant if its 95% bootstrap confidence interval does not cross the zero line. These analyses of change were conducted separately for daily, weekday and weekend composition; and the differences in changes

between weekdays and weekends were also tested. To identify the potential moderators of the change, subsequent models of daily movement behaviour composition were tested for additional interactions with sex, socio-economic status, body weight status (T1) or change score in pubertal progression.

The analyses of change in movement behaviour composition were not adjusted for school-level clustering effects for two reasons: 1) the existing mixed model analysis package in R (i.e., 'lme4') does not accommodate a multivariate variable as the outcome measure (e.g., the set of movement behaviour *ilrs* in this study); and 2) the calculated intra-correlation coefficients (ICCs) between movement behaviour *ilrs* and school-levels were considered low for both baseline (ranged from 0.06 to 0.11) and follow-up measures (ranged from -0.04 to 0.09), suggesting that the school-level influence on children's movement behaviour composition was small.

Changes in self-report measures of time spent in sedentary behaviours were assessed using paired sample t-tests, whereas changes in self-report domain-specific physical activity participation rates were assessed using McNemar tests. The differences in proportions of meeting/not meeting the individual and integrated movement guidelines were examined using McNemar or McNemar-Bowker test. A descriptive analysis was performed to examine the transition in adherence to each individual guideline from T1 to T2. Statistical significance was set at $p<0.05$.

5.3 Results

A total of 426 Year-6 children from 12 participating schools (three Government primary schools, three Government central schools, six independent schools) were invited to take part in the study, of which 135 (31.7%; 59 boys, 67 girls) provided consents and completed baseline assessments (Figure 5.1). Of these, 121 (89.6%) completed at least one of the two follow-up

assessments; and 79 (58.5%) completed all three assessments (22 (27.8%) had two follow-up data points during secondary school period). Eighty-three participants (61.5%), all recruited from the schools offering both primary and secondary education, met the accelerometer data inclusion criteria at the two time points of interest (T1 and T2; 87% of T2 data were from Follow-up 2 time point) and were included in the final analytical sample. The mean follow-up duration was 11±2 months.

The analytical sample did not differ from the excluded sample (n=52) with respect to BAZ (mean 0.38 vs. 0.44, p=0.763). However, they were of a higher SES than the excluded sample (mean SEIFA IRSD 1002 vs. 958, p<0.0001). There was a significant progression in pubertal development (p<0.0001) from T1 to T2 (Table 5.1). Only four participants (4.8%) had changed schools at T2.

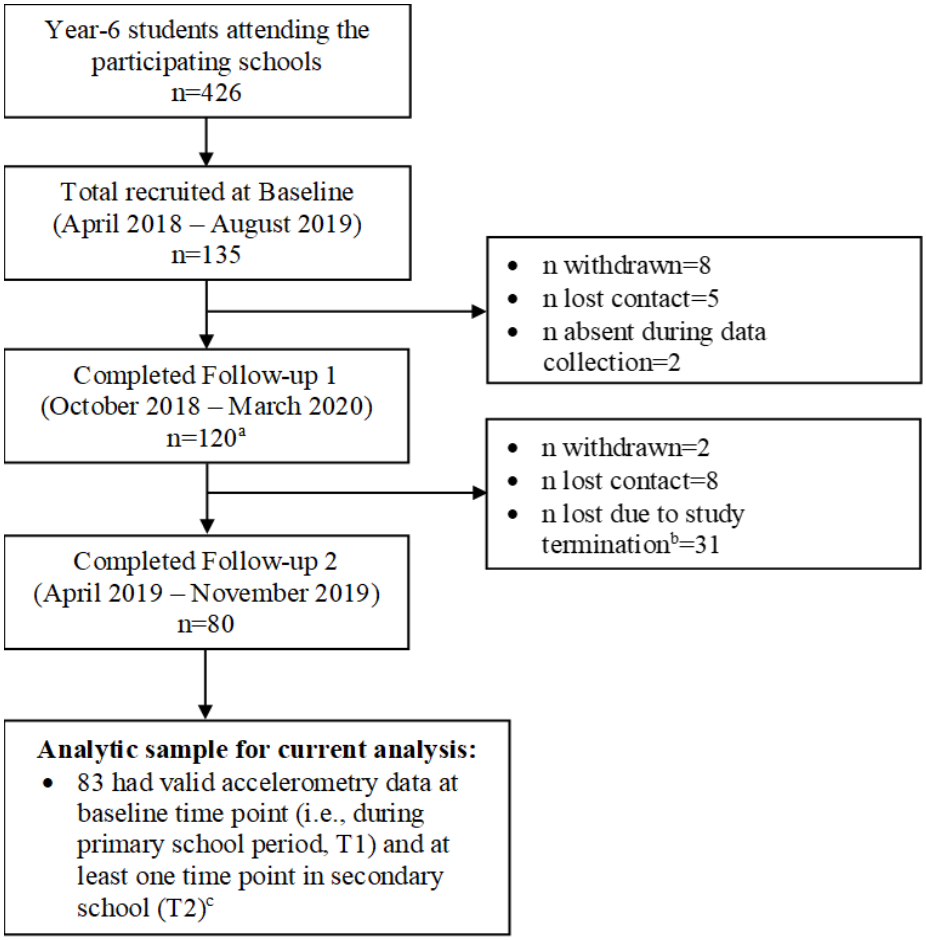

Figure 5.1 Flowchart of participants through the study

[a] During Follow-up 1, 86 participants were still enrolled in Year-6 (i.e., final year of primary school), while 34 had transitioned to Year-7 (i.e., first year of secondary school).
[b] Study was terminated in April 2020 as the University officially suspended all face-to-face data collection due to COVID-19.
[c] Secondary school data source (T2): Follow-up 1 time point, n=11 (13%); Follow-up 2 time point, n=72 (87%).

Table 5.1 Characteristics of the analytical sample

Characteristics	Primary school (T1)	Secondary school (T2)	p-value
Age (years)	11.8 (0.4)	12.8 (0.4)	-
Sex (girls), n (%)	50 (60.2)	-	-
SES (SEIFA IRSD score)	1003 (44)	-	-
BAZ[§]	0.36 (1.11)	0.41 (1.13)	0.478
Body weight status[§]			
Overweight/Obese, n (%)	24 (29.3)	26 (31.7)	0.754
Pubertal progression score	2.05 (0.53)	2.43 (0.65)	<0.0001

Data presented as mean (standard deviation) unless indicated.
[§] n=82 (one participant with missing anthropometric data).
Differences between T1 and T2 were tested using paired sample T-test or McNemar test.
SES=socio-economic status; SEIFA=Socio-Economic Indexes for Areas; IRSD=Index of Relative Socio-Economic Disadvantage scores; BAZ=body mass index z-score.

The daily 24-hour movement behaviour composition changed significantly from T1 to T2 ($F=12.1$, $p<0.0001$; Table 5.2) (see Appendix 5.1 for compositional variation matrix). Figure 5.2 shows that the change within each movement behaviour component was statistically significant. The mean log-ratio difference for daily durations of sleep, sedentary time, LPA and MVPA between T1 and T2 were -0.06, 0.10, -0.06 and -0.20, respectively (Figure 5.2). This means that the time spent in sleep, LPA and MVPA decreased by 6%, 6% and 20%, respectively; whereas sedentary time increased by 10% from T1 to T2.

There were no significant interactions between changes in daily movement behaviour composition and sex ($F=0.8$, $p=0.499$), socio-economic status ($F=0.2$, $p=0.897$), body weight status ($F=0.5$, $p=0.697$) or pubertal development ($F=0.5$, $p=0.675$). Further stratified analyses by day type revealed similar patterns but more pronounced changes in the weekday composition ($F=14.5$, $p<0.0001$) compared to that of weekends ($F=2.2$, $p=0.089$); and the day-type difference in changes were statistically significant ($F=8.6$, $p<0.0001$). Daily sleep onset and offset were approximately 48 min and 15 min later at T2, respectively; but sleep efficiency remained similar over time (86.9% vs. 87.0%) (Table 5.2).

Table 5.2 Changes in accelerometer-measured 24-hour movement behaviours and sleep characteristics from primary (T1) to secondary school (T2) time points

Variables	Overall daily		Weekdays		Weekends	
	T1	T2	T1	T2	T1	T2
24-hour movement behaviour composition						
Arithmetic mean (SD)[a]						
Sleep	544 (42)	513 (44)	536 (46)	501 (46)	565 (68)	545 (68)
SED	609 (64)	667 (63)	605 (68)	673 (62)	617 (93)	654 (93)
LPA	216 (34)	203 (31)	223 (34)	208 (31)	200 (54)	189 (49)
MVPA	71 (26)	57 (22)	76 (29)	58 (23)	58 (33)	52 (31)
Compositional mean (% of 24-hour)[b]						
Sleep	547 (38.0)	515 (35.8)	539 (37.4)	503 (34.9)	572 (39.7)	551 (38.3)
SED	611 (42.4)	670 (46.5)	608 (42.2)	677 (47.0)	623 (43.3)	660 (45.8)
LPA	215 (14.9)	202 (14.0)	222 (15.4)	208 (14.4)	196 (13.6)	186 (12.9)
MVPA	66 (4.7)	53 (3.7)	71 (5.0)	52 (3.7)	50 (3.4)	43 (3.0)
Sleep characteristics						
Onset (24Hour:Min)	21:55 (0:47)	22:43 (0:53)	21:51 (0:44)	22:41 (0:52)	22:00 (1:06)	22:49 (1:15)
Offset (24Hour:Min)	7:03 (0:38)	7:18 (0:41)	6:51 (0:33)	7:03 (0:38)	7:31 (1:17)	7:55 (1:05)
Efficiency (%)	86.9	87.0	86.8	86.9	87.1	87.3

Data presented as [a] arithmetic mean (standard deviation), which is calculated as the average min spent in each behaviour; and [b] compositional means (percentage of a 24-hour day), which is calculated as the geometric mean of each behaviour, linearly adjusted to collectively sum to 1440 min (24 h). SED=sedentary time; SB=sedentary behaviour; LPA=light-intensity physical activity; MVPA=moderate- to vigorous-intensity physical activity.

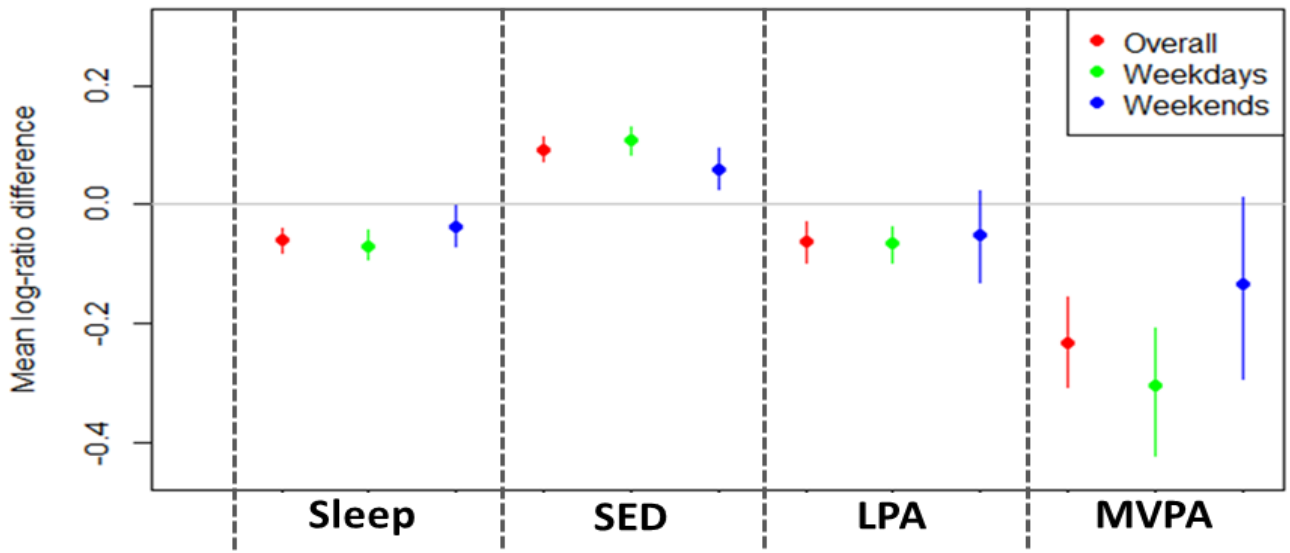

Figure 5.2 Bootstrapped mean and 95% confidence interval for the log-ratio differences of compositional means of movement behaviours between primary (T1) and secondary school (T2)

Note. The log-ratio difference was calculated by using the compositional means of behaviour at T2 as the numerator and the compositional means at T1 as the denominator (i.e., *ln*[T2/T1]). A positive value of the log-ratio difference* (i.e., above zero line) indicates that children spent more time in that behaviour at T2 than T1, and vice versa. The change within each movement behaviour component is considered significant if its 95% bootstrap confidence interval does not cross the zero line. (**A log-ratio difference of 0.10 for daily SED indicates that the time allocated to this behaviour component was increased by 10% from T1 to T2).*
SED=sedentary time; LPA=light-intensity physical activity; MVPA=moderate- to vigorous-intensity physical activity.

Self-report measures of sedentary behaviour showed a significant increase in the daily duration of recreational screen time (+45 min/day; p=0.001) and out-of-school educational activities (+25 min/day; p<0.0001) and a decrease in cultural activities (-21 min/day; p=0.004); but no significant changes were observed in social activities (p=0.144) or passive travel (p=0.083) (Table 5.3). Further stratified analyses by day type indicated that the changes in recreational screen time (p<0.0001 vs. p=0.498), out-of-school educational activities (p<0.0001 vs. p=0.060) and cultural activities (p=0.004 vs. p=0.056) were statistically significant during the weekdays but not weekends. No significant changes were observed in social activities (p=0.347 vs. p=0.183) or passive travel (p=0.087 vs. p=0.234) on both weekdays and weekends. There were no significant changes in participation rates across the five domains of physical activity (p=0.067-0.648).

The proportion of participants meeting individual behaviour guidelines decreased significantly from T1 to T2, with the greatest observed decrease in meeting the sleep guideline (60.2% vs. 30.1%; p<0.001); then the MVPA guideline (65.1% vs. 39.8%; p<0.001) and the screen time guideline (34.9% vs. 19.3%; p=0.002) (Table 5.4). A significant change was observed in adherence to the integrated movement guidelines (p<0.0001), whereby the proportion of participants meeting all three individual guidelines decreased (20.5% vs. 3.6%); while the proportion meeting none of the guidelines increased (14.5% vs. 36.1%). Further stratified analyses by day type showed that changes in the guidelines adherence rates (both individual and integrated guidelines) were only statistically significant on weekdays but not on weekends.

Table 5.3 Changes in self-report measures of sedentary behaviours and physical activity from primary (T1) to secondary school (T2) time points

Variables	Overall daily		Weekdays		Weekends	
	T1	T2	T1	T2	T1	T2
SB domains (min/d)						
Recreational screen time	197 (129)	242 (138)	160 (117)	217 (131)	290 (200)	304 (193)
Out-of-school educational activities	35 (37)	60 (47)	36 (35)	64 (55)	33 (61)	48 (59)
Social activities	45 (44)	52 (37)	34 (46)	40 (41)	73 (75)	84 (70)
Passive travel	46 (39)	38 (27)	45 (41)	37 (30)	47 (48)	40 (38)
Cultural activities	72 (70)	51 (55)	66 (70)	44 (47)	86 (86)	67 (90)
PA domains (n, %)						
Competitive team sports						
- inside school	51 (61.4)	47 (56.6)				
- outside school	47 (56.6)	44 (53.3)				
Competitive individual sports						
- inside school	31 (37.3)	24 (28.9)				
- outside school	41 (49.4)	35 (42.2)				
Organised but non-competitive PA	35 (42.2)	47 (56.6)				

SB=sedentary behaviour; PA=physical activity.

Table 5.4 Changes in participants' adherence to the Australian 24-Hour Movement Guidelines at primary (T1) and secondary school (T2) time points, n (%)

	Overall			Weekdays			Weekends		
	T1	**T2**	**p**	**T1**	**T2**	**p**	**T1**	**T2**	**p**
Individual guidelines									
Sleep	50 (60.2)	25 (30.1)	<0.001	46 (55.4)	13 (15.7)	<0.0001	55 (66.3)	45 (54.2)	0.110
MVPA	54 (65.1)	33 (39.8)	<0.001	58 (69.9)	35 (42.2)	<0.0001	34 (41.0)	27 (32.5)	0.281
ST	29 (34.9)	16 (19.3)	0.002	42 (50.6)	19 (22.9)	<0.0001	17 (20.5)	20 (24.1)	0.678
Combinations of integrated guidelines									
All three	17 (20.5)	3 (3.6)	<0.0001	20 (24.1)	3 (3.6)	<0.0001	5 (6.0)	7 (8.4)	0.110
Any two	28 (33.7)	15 (18.1)		29 (34.9)	11 (13.3)		24 (28.9)	18 (21.7)	
Any one	26 (31.3)	35 (42.2)		28 (33.7)	36 (43.4)		43 (51.8)	35 (42.2)	
None	12 (14.5)	30 (36.1)		6 (7.2)	33 (39.8)		11 (13.3)	23 (27.7)	

The changes in proportions of meeting the guidelines between T1 and T2 were examined using McNemar or McNemar-Bowker test.
MVPA=moderate- to vigorous-intensity physical activity; ST=screen time.

More than half the participants shifted from meeting to not meeting the individual guidelines or remained non-adherent (sleep=69.9%; MVPA=60.2%; screen time=80.7%) over the school transition period (Table 5.5).

Table 5.5 Transition in adherence to the 24-Hour Movement Guidelines during the transition from primary (T1) to secondary school (T2)

Transition in adherence to the movement guidelines	**Sleep**	**MVPA**	**ST**
Not meeting → Not Meeting	26 (31.3%)	24 (28.9%)	52 (62.6%)
Not meeting → Meeting	7 (8.4%)	5 (6.0%)	2 (2.4%)
Meeting → Not meeting	32 (38.6%)	26 (31.3%)	15 (18.1%)
Meeting → Meeting	18 (21.7%)	28 (33.8%)	14 (16.9%)

MVPA=moderate- to vigorous-intensity physical activity; ST=screen time.

5.4 Discussion

This study found that 24-hour movement behaviour patterns changed significantly across the primary to secondary school transition, with increased time spent sedentary and decreased time in sleep, LPA and MVPA on both weekdays and weekends. The observed increase in sedentary time may be due in part to an increase in recreational screen time and out-of-school educational activities. No significant changes were found in domain-specific physical activity participation. These behavioural changes are reflected in decreased adherence to the individual and integrated 24-hour movement guidelines, with the largest decline observed in the sleep guideline. The change in weekday movement behaviour composition was significantly more prominent compared to that of the weekends. No moderating effects were found for child's sex, SES, body weight status or pubertal development.

These results are consistent with previous findings (Chong et al. 2020; Pearson et al. 2017) and contribute additional evidence that there is a shift towards 'unhealthy' 24-hour movement behaviour composition during the transition from primary to secondary school. The increase in sedentary time was compensated by a concurrent decrease in both sleep and physical activity time-use components, indicating the need for a 'full-composition' intervention approach during this school transition period. The larger changes in weekday behaviours compared to weekend behaviours may be explained by the observed day-type differences in movement behaviour composition during the primary school period. Children had already accumulated more sedentary time and less LPA and MVPA on weekends relative to weekdays, suggesting a ceiling effect that limits room for further changes in the weekend composition. These findings indicate that early interventions (prior to school transition) targeted at both weekdays and weekends may prevent the development of unhealthy movement behaviour patterns in children; but weekdays warrant particular attention for interventions targeting the primary to secondary school transition period due to the greater behavioural changes observed.

Consistent with previous research (Pearson et al. 2017), the domain-specific findings suggest that increased recreational screen use and out-of-school educational activities (including time spent doing homework) may have partly contributed to the increase in sedentary time during the primary to secondary school transition; although it should be noted that the domain-specific measure quantified the time spent sedentary during a typical week and was not time-matched with the accelerometer data. Other studies have also reported an increased engagement in sedentary activities during school hours (specifically during recess/lunchtime) (Morton et al. 2016; Marks et al. 2015), which may be attributed to the differences in the school's physical (e.g., availability of facilities), social (e.g., school's encouragement and support to physical activity participation) and/or policy (e.g., recess or break length) environments between primary and secondary school settings. Alternatively, it may be due to an increase in the autonomy of behavioural choices as children age. Together, these results underscore the continued importance of developing effective strategies for preventing excessive sedentary behaviours in children, both within and outside of school settings.

There was a marked decrease in sleep duration over the school transition period, primarily due to later sleep onset timing. Such changes may be the result of an increase in recreational screen time (Hale & Guan 2015), and/or the additional academic demands (i.e., more homework) as children entering secondary school (Evans-Whipp & Gasser 2019), which are also observed in this study. Interestingly, sleep efficiency remained similar over time despite the decrease in duration. This is consistent with a meta-analysis (Ohayon et al. 2014) which found no significant age-related changes in polysomnography- or actigraphy-assessed sleep efficiency from childhood to adolescence. Another important observation of this study is that there was a large decline (~50%) in adherence to the sleep duration guidelines, with only one-third of children meeting the recommended sleep duration after transition to secondary school. This is particularly concerning given the known associations between shorter sleep duration and adverse health outcomes (e.g., higher adiposity levels, poorer mental health) (Chaput et al.

2016), and therefore underlines the need to integrate sleep health promotion into the designs of future lifestyle interventions targeting the primary to secondary school transition period. Our findings suggest that school-level intervention strategies (e.g., delaying school start times, integrating sleep health literacy into school curriculum) (Chaput 2019) may be particularly beneficial for improving sleep in this population due to a greater change in duration and also shorter sleep observed on weekdays than on weekends. This is supported by recent experimental evidence demonstrating that delaying school start time by 25 to 60 min could help increase adolescents' total sleep times from 25 to 77 min per weeknight and improve other sleep and health characteristics (e.g., reduced daytime sleepiness, depression) (Minges & Redeker 2016).

The decreases in LPA and MVPA are likely due to the concurrent increase in sedentary behaviour taking time from more active past-times. Previous research has shown that changes in physical activity may vary by time segments and domains, with decreases often occurring during school breaks (i.e., recess and lunchtime) and after-school/leisure hours (e.g., decrease in sports participation) (Chong et al. 2020; Remmers et al. 2020; Morton et al. 2016). There is also evidence of an increase in active school travel but decrease in active travel during leisure time or weekends (Chong et al. 2020; Remmers et al. 2020). Although not statistically significant, our study did observe a small decrease in the self-reported participation rates for competitive team and individual sports (both inside school and outside school) and time spent in passive travel. The decrease in physical activity during this transition period may be explained by a number of factors, including intrapersonal factors (e.g., skills and aptitudes), social factors (e.g., parental or friend support), school factors (e.g., provision of physical activity opportunities) and neighbourhood characteristics (e.g., presence of social spaces for physical activity, as suggested by previous research (McGaughey et al. 2020; Pate et al. 2019; Morton et al. 2016).

In parallel with the changes observed in movement behaviour composition, the proportion of children meeting the individual and integrated movement guidelines significantly declined over the school transition period, particularly on weekdays. It is worth noting that, while the largest

decline was observed in the sleep guideline, the screen time guideline showed the lowest adherence rate at both primary and secondary school time points (i.e., approximately half of those for sleep or MVPA guidelines). In addition, more than half the children were identified as having shifted from meeting to not meeting the individual guidelines or remained non-adherent. This is of concern as non-adherence with the movement guidelines has been shown to be adversely associated with health and developmental outcomes (Rollo, Antsygina & Tremblay 2020). Further research is required to identify the factors that may predict these unfavourable shifts in guidelines adherence status to inform future policy and interventions efforts.

This study found that the change in daily movement behaviour composition was not moderated by child's sex, SES, body weight status or pubertal development. This may be due to the small sample size, causing inadequate statistical power to detect significant effects in the current analysis. A previous Australian cohort study suggests that a complete change in the school environment may result in a greater change in children's activity patterns during this transition period (Marks et al. 2015). For example, children who changed schools were reported to spend more time on screens for leisure and were less likely to engage in active school transport than those who did not; although no differences were observed in the accelerometer-measured LPA, MVPA or sedentary time between the two groups (Marks et al. 2015). The differences in changes may be partly explained by the less supportive environment for physical activity (e.g., equipment accessibility outside of physical education lessons) in secondary schools compared to primary schools (Marks et al. 2015). Although the present study sample did not allow for a direct comparison of changes in movement behaviours between the two transition groups (i.e., only 5% of children had changed schools at T2), it was hypothesised that the changes would be greater for children who had gone to a different secondary school with a less/more supportive environment for physical activity compared to their previous primary schools.

This is the first study to assess the impact of the primary to secondary school transition on all components of the 24-hour movement behaviour continuum. Strengths of this study include the incorporation of both device-based and self-report measures to provide a more complete characterisation of behavioural changes; and the use of CoDA to account for the co-dependency between movement behaviours. However, the study results should be interpreted cautiously due to the small sample size and the use of a convenience sampling approach. It is important to note that the analytical sample comprised mostly of children (~95%) attending the same school for primary and secondary education and had a higher SES than the excluded participants (due to missing data), thus limiting the generalisability of the findings.

5.5 Conclusion

This study demonstrates an unfavourable change in the 24-hour movement behaviour composition (i.e., increased sedentary time and decreased sleep, LPA and MVPA) during the transition from primary to secondary school, particularly on weekdays. The observed increase in sedentary time may be partly due to an increase in recreational screen time and out-of-school educational activities at secondary schools. No significant changes were found in domain-specific physical activity participation. Furthermore, there was a substantial decline in adherence to the 24-hour integrated movement guidelines. These findings emphasise the critical need for an integrated intervention approach to support children to develop and maintain healthy movement behaviour habits throughout the school transition period. Specifically, interventions targeting the maintenance of movement behaviours' levels on weekdays may be beneficial due to the greater behavioural changes observed, relative to weekends.

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Chapter 6: Changes in 24-hour domain-specific movement behaviours and their associations with children's psychosocial health during the transition from primary to secondary school: A compositional data analysis

Chapter 5 demonstrated that children spent significantly more time being sedentary and less time in sleep and physical activity during a 24-hour period as they made the transition from primary to secondary school. These behavioural changes were also reflected in decreased adherence rates to the Australian 24-Hour Movement Guidelines, with the largest decline observed in meeting the sleep guideline. To inform future intervention development, a more thorough understanding of the changes across different domains of movement behaviours is warranted. Further, given the evidence on the potential influence of movement behaviours on children's psychosocial health (as described in Chapter 2: Section 2.7), it is important to determine whether the behavioural changes that occur during this school transition period may have an impact on children's psychosocial development. This chapter set out to address the gaps in these research areas by investigating the following research questions:

Research Question 1:

How does the distribution of time spent in different intensities and domains of 24-hour movement behaviours change across the transition from primary to secondary school?

Sub-research question:

1.3 Is the change in 24-hour movement behaviour composition moderated by a change in the school environment (i.e., transitioning to a new secondary school)?

Research Question 2:

Are 24-hour movement behaviours associated with children's psychosocial health during the transition from primary to secondary school?

Sub-research question:

2.1 Is the change in 24-hour movement behaviour composition associated with changes in children's psychosocial health during the school transition period?

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6.1 Background

Time spent in physical activity (Biddle et al. 2019; Poitras et al. 2016), sedentary behaviour (Carson et al. 2016a) and sleep (Chaput et al. 2016) can have a profound effect on child and adolescent health. Until recently, these movement-related physical behaviours (hereafter collectively referred to as movement behaviours) have largely been studied in isolation (Pedišić, Dumuid & Olds 2017). However, emerging evidence suggests that different combinations or compositions of the movement behaviours within a 24-hour period may affect health differently (Rollo, Antsygina & Tremblay 2020; Saunders et al. 2016). Because these movement behaviours occur within a finite period of time, they are inherently multi-collinear and co-dependent (Chastin et al. 2015). Therefore, the daily time allocated to different movement behaviours and their associations with health outcomes should be analysed and interpreted using an integrated rather than segregated approach (Pedišić, Dumuid & Olds 2017; Chastin et al. 2015; Chaput et al. 2014). This realisation has prompted the introduction of a new 24-hour movement behaviour paradigm (Rosenberger et al. 2019; Pedišić, Dumuid & Olds 2017; Chaput et al. 2014), which emphasises the importance of considering all movement behaviours across the 24-hour day as a collective component for promoting and maintaining holistic health and wellbeing.

Over the past decade, several population-based studies have demonstrated unfavourable age-related changes in individual movement behaviours, with an increasing prevalence of sedentary behaviour (Kontostoli et al. 2021), decreasing physical activity (Kemp et al. 2020; Farooq et al. 2017) and sleep duration (Evans-Whipp & Gasser 2019) from childhood into adolescence. Such behavioural changes may be partly explained by the influence of the school environment (Evans-Whipp & Gasser 2019; Morton et al. 2016a), as most children and adolescents spend a large proportion of their waking hours at school. The transition from primary (ages ~5-12y) to secondary school (ages ~12-17y) is a particularly important education-related life transition where significant behavioural changes occur (Chong et al. 2020; Pearson et al. 2017). For most

children, this transition is accompanied by significant environmental changes (i.e., physical, social and/or academic) (McGaughey et al. 2020; Morton et al. 2016b; Hanewald 2013), which co-occur with puberty-associated developmental changes (e.g., biological and emotional) (Patton & Viner 2007) that may interact to influence their movement behaviours. Recent systematic reviews suggest that children spend more time engaging in sedentary behaviour (Pearson et al. 2017) and less time in physical activity (Chong et al. 2020) as they make the transition from primary to secondary school. Another study which investigated the changes in the 24-hour composition of intensity-specific movement behaviours during this school transition period further demonstrated that the increase in overall sedentary time was compensated by a concomitant decrease in both physical activity and sleep duration (Chong et al. 2021a). However, to the best of the authors' knowledge, no known study has examined concurrent changes in time spent in different domains of movement behaviours (e.g., screen time, chores, transport) (Olds, Maher & Dumuid 2019) across the whole day during this school transition period. This information could provide a more thorough understanding of children's daily movement behaviour patterns and help identify the behavioural domains that are most in need of targeted interventions.

Given the current evidence on the health implications of time spent in 24-hour movement behaviours (Rollo, Antsygina & Tremblay 2020; Carson et al. 2016; Chaput et al. 2016; Poitras et al. 2016; Saunders et al. 2016), there is good reason to believe that the behavioural changes that occur during the transition from primary to secondary school may have an impact on children's health and wellbeing. Of particular interest are the psychosocial health aspects, which are highly susceptible to change during this period (Evans, Borriello & Field 2018; Lester & Cross 2015). However, there is a lack of evidence regarding the contributions of movement behaviours to children's psychosocial functioning during this key transition. Indeed, the combined effects of 24-hour movement behaviours on children's and adolescents' psychosocial health are under-researched (Rollo, Antsygina & Tremblay 2020; Sampasa-Kanyinga et al.

2020). In particular, only a few studies have examined the full 24-hour movement behaviour time-use composition (i.e., time spent in sleep, sedentary behaviour and physical activity combined) in relation to psychosocial health outcomes (e.g., emotional and behavioural problems) cross-sectionally (Fairclough et al. 2021; Carson et al. 2016b) or longitudinally (Chong et al. 2021b – see Chapter 7) using adequate statistical techniques that account for the compositional properties of movement behaviour data (Chastin et al. 2015). The limited available evidence suggests that the 24-hour movement behaviour composition is associated with psychosocial health outcomes in children and adolescents, with higher sedentary time and shorter sleep duration (relative to other behaviours) being associated with poorer outcomes (Chong et al. 2021b; Fairclough et al. 2021; Carson et al. 2016b). It is worth noting that the aforementioned studies focused only on the intensity-specific movement behaviour composition (i.e., sleep, sedentary time, light-intensity physical activity and moderate- to vigorous-intensity physical activity) (Chong et al. 2021b; Fairclough et al. 2021; Carson et al. 2016b). As there is evidence of domain-specific associations between individual movement behaviours and psychosocial health in children (White et al. 2017; Carson et al. 2016a), it is important to further explore the combined and relative associations of daily domain-specific movement behaviours with health outcomes. This information will provide an indication of the behavioural domains most likely to affect children's psychosocial development and that should be considered when developing health interventions, policies and guidelines.

The primary aims of this study were to describe the change in 24-hour domain-specific movement behaviour composition during the transition from primary to secondary school; and to determine whether the change in movement behaviour composition was associated with change in psychosocial health. In Australia, the transition to secondary school may or may not require a change in school environment, depending on the type of primary school system (e.g., non-combined school versus combined primary-secondary school). Given the reported associations between the school environment and children's movement behaviours (Morton et

al. 2016a), this study further explored if change in movement behaviour composition was moderated by change in the school environment (i.e., moved to a new secondary school vs. remained in the same school) during this school transition period.

6.2 Methods

6.2.1 Study design and participants

Data were drawn from the Longitudinal Study of Australian Children (LSAC), a nationally representative longitudinal study of child development in Australia (Australian Institute of Family Studies 2018). LSAC began in 2004 with two cohorts of children recruited when they were aged 0-1y (B-cohort; 5,107 children) and 4-5y (K-cohort; 4,983 children), respectively (Australian Institute of Family Studies 2018). A two-stage clustered sampling strategy was used to randomly select children from 311 postcodes through Australia's national healthcare database (Soloff, Lawrence & Johnstone 2005). Data were collected biennially from participants and their parents and teachers via face-to-face interviews, self-report questionnaires, and direct observations and assessments (Australian Institute of Family Studies 2018). Ethical approval for the LSAC study was obtained from the Australian Institute of Family Studies Ethics Committee and informed consent was obtained from all participants. Access to LSAC data for use in this study was granted by the National Centre for Longitudinal Data.

This study utilised data collected from the LSAC K-cohort during Wave 4 (2010) and Wave 5 (2012) when participants were aged 10-11y and 12-13y, respectively. These waves were chosen as the follow-up period coincides with the transition from primary to secondary school in Australia. Only participants who met the following criteria were included in the analytical sample: 1) enrolled in primary school at Wave 4 (referred to hereafter as T1) and in secondary school at Wave 5 (referred to hereafter as T2); 2) provided valid time-use diaries on the same type of day (i.e., school day or non-school day) at both time points; and 3) had no missing data on any of the study variables.

6.2.2 Measures

i. 24-hour domain-specific movement behaviours

Time spent in different domains of movement behaviours across a 24-hour period was measured using a time-use diary instrument (Corey et al. 2004). Compared with device-based monitoring systems (e.g., accelerometry), time-use diaries allow the collection of information about the domains and contexts in which daily movement behaviours occur (Bauman, Bittman & Gershuny 2019). At both time points, participants were mailed an open-ended, paper-based diary with instructions to record their sleep schedule (i.e., wake-up time and go-to-bed/sleep time) and the start times of all activities they engaged in during the waking period on the day prior to their scheduled home interview (Corey et al. 2014). It was assumed that each activity ended at the start time of the subsequent activity, with the final activity ending at the bed/sleep time. The interviewers then transposed the recorded activities based on a predetermined coding framework to yield a comparable set of activities across all participants' diaries (Corey et al. 2014). Additional information about the contexts of the activities (e.g., where they were, who they were with) was also collected during the interview. While participants were allowed to record up to six secondary activities concurrently, it was not possible to determine how each allocated time window could be distributed among multiple concurrent activities. Therefore, the current analysis focused only on the primary activity recorded for each time window.

All time-use diaries were checked and processed following a standard protocol as described in Appendix 6.1. A time-use diary was considered as invalid and excluded from the analysis if it had: 1) ≤12 h of diary activities (calculated as the difference in duration between the start time of the first and last activity); and 2) missing or invalid activity times (e.g., improbable wake-up or bed times). The time spent in each recorded activity was calculated and aggregated into eight distinct domains (referred to hereafter as activity domains): Self-care/Domestic, Physical Activity, Social, Education, Recreational Screen Use, Quiet Time, Sleep and Passive Transport. The operationalisation of these domains was determined by consulting previous time-use diary

research (Kemp et al. 2020; Olds, Maher & Dumuid 2019). It is important to note that some of the diaries had undefined period(s) of activity time (e.g., activity coded as 'Others', the time between wake-up time and the start of the first recorded activity) (mean duration of 16±30 min/day at T1 and 16±29 min/day at T2), which could not be assigned to any of the activity domains and were therefore excluded from the analysis of movement behaviour composition. To account for the missing durations, the mean durations of all activity domains were linearly adjusted to collectively sum to 24 h for descriptive purposes. The complete list of the diary activity codes and their classification into the eight domains can be found in Appendix 6.2.

Considering the potential influence of school attendance on participants' movement behaviours (Olds, Maher & Dumuid, 2019; Brazendale et al. 2017), only those who had provided diaries reflecting the same day type at both time points were included in the present analysis: two school days (i.e., completed the diaries on a weekday with at least one of the recorded activities occurring at school) or two non-school days (i.e., not meeting the school day's criteria; weekends and holidays were included).

ii. Psychosocial health measures

The Strengths and Difficulties Questionnaire (SDQ) is a brief behavioural screening questionnaire that measures the emotional and behavioural aspects of psychosocial health among children and adolescents aged 4 to 17 years (Goodman 1997). It consists of 25 items divided into five subscales: emotional symptoms, conduct problems, hyperactivity, peer relationship problems and prosocial behaviour. Each item is rated on a 3-point Likert scale: 'not true', 'somewhat true', or 'certainly true'. 'Somewhat true' is always scored as 1, but the scoring of 'not true' and 'certainly true' varies across items (0 or 2). Following the recommendations for low-risk or general population studies (Goodman, Lamping & Ploubidis 2010), the three-subscale model of SDQ (i.e., internalising problems – sum of emotional symptoms and peer problems subscales; externalising problems – sum of conduct problems and

hyperactivity subscales; and prosocial behaviour) was employed in this study. A total difficulties score was also calculated by summing the scores of the internalising and externalising problems subscales. Higher scores indicate greater levels of problems for the internalising (score range 0-20) and externalising problems (score range 0-20) subscales and total difficulties score (score range 0-40); and fewer problems for the prosocial behavior subscale (range 0-10). In this study, the self-report version of the SDQ was used, which has demonstrated adequate psychometric properties for use in children and adolescents (Van Roy, Veenstra & Clench-Aas 2008; Muris, Meesters & van den Berg 2003). The questionnaire was administered via an audio computer-assisted self-interview during the home interview (Australian Institute of Family Studies 2018).

iii. Control variables

The following were included as covariates: socio-demographic characteristics (participant's sex, main language spoken at home and family socio-economic position index), physical health and development (body mass index z-score (BAZ), pubertal progression and general health status), bullying, the change in school environment and the season of measurement. These variables were selected due to their associations with movement behaviours (Rollo et al. 2020) and/or psychosocial health (Evans, Borriello & Field 2018; Thomas et al. 2017; Mensah et al. 2013) in children and adolescents. These data were collected during the home interview (Australian Institute of Family Studies 2018). The descriptive information about each variable is provided in Table 6.1.

Table 6.1 Descriptive information about the covariates included in the analysis

Variables	Descriptions
Socio-demographic characteristics	
Sex	Determined at Wave 1 of LSAC (Boys/Girls).
Main language spoken at home	Parent's report of whether the child speaks a language other than English at home (Yes/No).
Family socio-economic position index	A composite index derived by LSAC based on family annual income, parents' educational attainment and occupational status (Baker, Sipthorp & Edwards 2017).
Physical health and development	
Body mass index z-score (BAZ)	Calculated using body weight and height measurements based on the World Health Organization growth reference data (de Onis et al. 2007).
Pubertal progression	Based on parent's assessment of the child's development on five puberty indicators: three general (i.e., growth spurt, body hair growth, skin changes) and two sex-specific (boys: facial hair growth and voice changes; girls: breast development and the onset of menarche) (Petersen et al. 1988). Each indicator was rated on a 4-point scale: 1 'Has not started yet' (or 'No' for menarche item), 2 'Has barely started', 3 'Has definitely started', 4 'Seems completed' (or 'Yes' for menarche item). An average score was derived from all five items and used as a measure of pubertal progression.
General health status	Self-reported by the child using a five-point rating scale (1 'Excellent', 2 'Very Good', 3 'Good', 4 'Fair', 5 'Poor').
Other factors	
Bullying	Parent's report of whether the child had been bullied at school (including travel to and from school) in the last 12 months (Yes/No).
The change in school environment	Parent's report of whether the child had changed schools since the previous wave of data collection (Yes/No). Additional information, such as the main reason for the change in schools (parent's report) and whether the child had experienced difficulties in changing schools (child's report), were also gathered and used for descriptive purposes in this study.
Season of measurement	Derived from the date of interview included in the LSAC dataset and classified into four seasons (Spring, Summer, Autumn, Winter) as per the Australia's climate glossary (Australian Bureau of Meteorology n.d.).

6.2.3 Statistical analyses

Standard statistical analyses were performed in IBM SPSS Statistics for Windows (version 26; IBM Corp., Armonk, New York). Descriptive statistics (mean, standard deviation, frequency and percentage) were calculated to summarise participant characteristics. Differences in descriptive characteristics between the analytical and excluded samples were analysed using independent t-tests. Changes in characteristics of the analytical sample from T1 to T2 were analysed using paired sample t-tests.

A CoDA approach was implemented in this study to address the compositional nature of movement behaviour data derived from the time-use diaries. All CoDA analyses were performed in R (version 3.6.2; R Foundation for Statistical Computing, Vienna, Austria) using the following packages: 'compositions' (version 2.0.0) (van den Boogaart & Tolosana-Delgado 2008), 'robCompositions' (version 2.3.0) (Templ, Hron & Filzmoser 2011), 'zCompositions' (version 1.3.4) (Palarea-Albaladejo & Martín-Fernández 2015). Following CoDA procedures (Dumuid et al. 2018; Chastin et al. 2015), each participant's eight-part movement behaviour composition was expressed as a set of seven isometric log-ratio coordinates (*ilrs*). The *ilrs* contained the relative information about the overall movement behavior composition. However, before the *ilrs* could be computed, any zero values in any of the activity domains needed to be dealt with. In this study, all zeros were classified as 'rounded' because it seemed feasible that every child would eventually accumulate some time in each of the domains if the recording period was longer (e.g., a week) (Martín-Fernández & Thió-Henestrosa 2006) (see Appendix 6.3 for further information about the presence of zero values in the activity domains). The movement behaviour data were reprocessed to impute all the zero values using the log-ratio Expectation-Maximization algorithm (Palarea-Albaladejo, Martín-Fernández & Gómez-García 2007), as suggested by Rasmussen et al. (2020). Once the movement behaviour compositions were expressed as a set of *ilrs*, standard statistical methods were applied as described below.

The change in overall movement behaviour composition was examined using repeated measures MANOVA; where the interactions between time points (T1 and T2) and the set of *ilrs* (representing movement behaviour composition) were tested. To assess the changes of each activity domain within the composition, the log-ratio difference of compositional means between the time points (*ln*[T2/T1]) and its 95% bootstrap confidence interval were calculated for each domain and plotted for interpretation (Martín-Fernández, Daunis-i-Estadella & Mateu-Figueras 2015). Preliminary analysis indicated that there was a significant interaction between time points, movement behaviour *ilrs*, diary reporting day type and participant's sex ($F=2.6$, $p=0.012$). Therefore, the analyses of change in movement behaviour composition were stratified by school day and non-school day samples, separately for boys and girls. However, no interaction effect was observed with the season of measurement ($F=1.0$, $p=0.408$). The moderating influence of the change in school environment on movement behaviour composition was examined by testing its interaction with the time points, movement behaviour *ilrs*, diary reporting day type and participant's sex.

The associations between changes in movement behaviour composition (i.e., difference in *ilrs* between T1 and T2) (independent variables) and changes in each psychosocial health outcome (dependent variables) were examined using multiple linear regression models. The analyses were stratified by boys and girls (regardless of diary reporting day type) due to an observed significant interaction with sex in two of the four models (internalising problems: $F=2.1$, $p=0.038$; prosocial behaviour: $F=2.4$, $p=0.021$). All models were adjusted for socio-demographic characteristics, BAZ and corresponding psychosocial health outcome at T1; the change in general health rating and pubertal progression scores between T1 and T2; and T2 measures of bullying and the change in school environment. If statistical significance was observed ($p<0.05$), subsequent models (each with a different set of *ilrs* that included a different domain as the numerator of the first *ilr*) were conducted to determine which activity domain(s) was related to the change in the psychosocial health outcome (Chastin et al. 2015). To aid the

interpretation of the associations, the above-mentioned models were used to estimate the changes in psychosocial health outcomes in association with a longitudinal reallocation of 30 min to the activity domain(s) of interest from the remaining domains (i.e., one-for-remaining time reallocations) using the mean movement behaviour composition at T1 as reference (Lewthwaite et al. 2019). Effect sizes were calculated by dividing the estimated changes in the health outcome (i.e., the estimates based on new composition minus the estimates based on the mean composition at T1) by the pooled standard deviations of the health outcome at T1 and T2 (Lewthwaite et al. 2019).

6.3 Results

A total of 4,169 and 3,956 participants completed the assessment at Wave 4 and Wave 5 of the LSAC study, respectively. Of these participants, 2,539 (1,262 boys, 1,277 girls) provided valid time-use diaries at both waves. A further 1,630 participants were excluded from this study due to not meeting the data inclusion criteria (see Figure 6.1 for the reasons of exclusion), leaving a sample size of 909 participants (35.8%) for the current analysis.

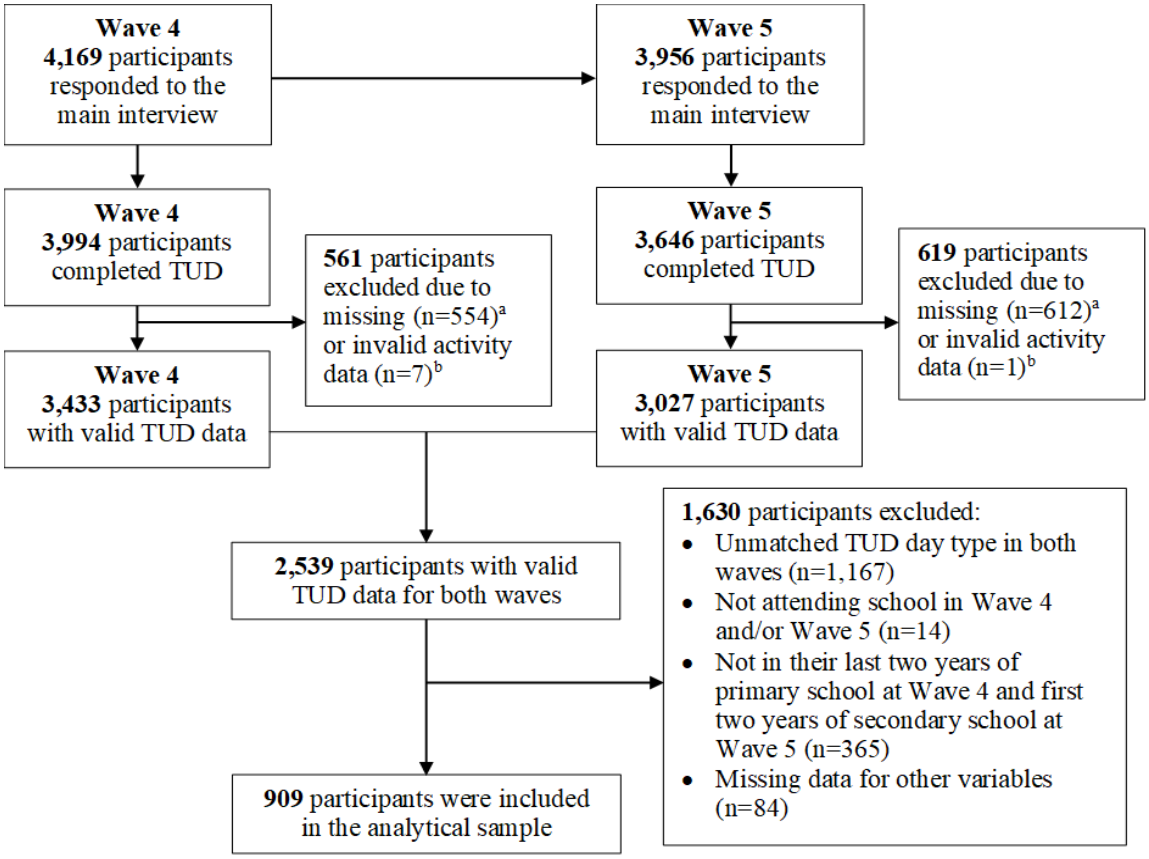

Figure 6.1 Flowchart illustrating the reasons for exclusion from the analytical sample

Note. TUDs were excluded due to having: [a] ≤12 h of diary activities (Wave 4=534; Wave 5=611) or undefined activity times recorded between midnight and wake-up time (Wave 4=20; Wave 5=1); or [b] improbable wake-up time (i.e., before 4:00AM) (Wave 4=7, Wave 5=7). TUD=time-use diary.

The analytical sample comprised a lower proportion of boys than girls compared to the excluded sample (46.9% vs. 51.3%; p=0.033), but did not differ significantly in terms of family socio-economic position (mean index=0.12 vs. 0.10; p=0.722) or main language spoken at home (% non-English speaking=10.3 vs. 8.7; p=0.185). The descriptive characteristics of the analytical sample at the two time points of interests (T1 and T2) are summarised in Table 6.2. Most participants (n=783; 86.1%) had changed schools from T1 to T2, mainly due to the change from primary to secondary school (93.9%) which is common in the Australian education system. Of this subsample, 13.4% (n=105) reported having difficulties with the transition to a new secondary school (e.g., making new friends, missing friends from previous schools and being required to do more homework).

Table 6.2 Characteristics of the analytical sample

Characteristics	T1	T2	p-value
Sex (boys), n (%)	426 (46.9)	-	
Age (in years)	10.4 (0.5)	12.5 (0.5)	
Family socio-economic position index	0.12 (0.99)	-	
Main language spoken at home (non-English), n (%)	79 (8.7)	-	
BAZ	0.62 (1.25)	0.67 (1.16)	0.002
Pubertal progression score	1.66 (0.49)	2.33 (0.74)	<0.0001
General health rating	1.70 (0.74)	1.65 (0.74)	0.077
Being bullied at school in the last year, n (%)[a]	-	234 (25.7)	

Data presented as mean (standard deviation) unless indicated. Differences in health characteristics between T1 and T2 were tested using paired sample t-test.
[a] Data at T1 were not reported as they were out-of-scope for this study.
BAZ=body mass index z-score.

Table 6.3 presents the descriptive statistics of 24-hour domain-specific movement behaviour composition (see Appendix 6.4 for compositional variation matrix). A larger proportion of the analytical sample (67.4%) had completed their time-use diaries on a school day at both time points. There was a significant change in overall movement behaviour composition from T1 to T2 in both school day ($p<0.0001$ for both boys and girls) and non-school day samples (boys=$p<0.0001$; girls=$p<0.001$). Among the school-day sample (Figure 6.2a), there were significant increases in time spent in the Social (boys=+189%; girls=+104%), Recreational Screen Use (boys=+35% ; girls=+30%) and Passive Transport domains (boys=+20%; girls=+26%), and decreases in Physical Activity (boys=-50%; girls=-63%), Quiet Time (boys=-58%; girls=-51%) and Sleep (boys=-10%; girls=-13%) in both boys and girls. Girls also spent significantly more time in the Self-care/Domestic domain (+10%) at T2. Among the non-school day sample (Figure 6.2b), time spent in the Social domain (boys=+105%; girls=+110%) significantly increased, while time spent in Sleep (boys=-8%; girls=-14%) decreased in both boys and girls. Boys also spent significantly more time in Recreational Screen Use (+38%) but less time in Education (-42%) and Quiet Time (-82%); whereas girls spent significantly less time in Passive Transport domain (-31%) at T2. Subsequent interaction analysis indicated that the change in overall movement behaviour composition was not moderated by the change in school environment ($F=0.6$, $p=0.759$).

Table 6.3 24-hour domain-specific movement behaviour composition (min/day) and sleep schedule at primary (T1) to secondary school (T2) time points

Domains	School day sample (n=613)[a]				Non-school day sample (n=296)[b]			
	Boys (n=276)		Girls (n=337)		Boys (n=150)		Girls (n=146)	
	T1	T2	T1	T2	T1	T2	T1	T2
Arithmetic mean (SD)[c]								
Self-care/Domestic	113 (52)	116 (50)	130 (62)	141 (56)	138 (87)	141 (110)	174 (99)	186 (112)
Physical Activity	132 (79)	102 (84)	115 (85)	83 (77)	188 (146)	158 (124)	168 (144)	145 (133)
Social	23 (49)	35 (50)	33 (50)	44 (62)	34 (67)	47 (75)	38 (70)	60 (98)
Education	339 (72)	355 (88)	345 (80)	380 (104)	24 (65)	15 (44)	28 (73)	34 (72)
Recreational Screen Use	134 (94)	168 (106)	103 (85)	124 (97)	280 (171)	357 (173)	237 (155)	238 (165)
Quiet Time	47 (73)	42 (55)	53 (79)	46 (53)	100 (113)	75 (100)	105 (116)	134 (142)
Sleep	594 (58)	542 (74)	599 (51)	532 (78)	601 (78)	571 (96)	604 (76)	574 (135)
Passive Transport	62 (54)	75 (57)	67 (53)	83 (65)	75 (75)	77 (90)	86 (89)	69 (80)
Compositional mean (% of 24-hour)[d]								
Self-care/Domestic	116 (8.0)	125 (8.7)	137 (9.5)	159 (11.0)	143 (9.9)	146 (10.1)	202 (14.0)	233 (16.2)
Physical Activity	111 (7.7)	67 (4.7)	88 (6.1)	49 (3.4)	147 (10.2)	118 (8.2)	104 (7.2)	93 (6.5)
Social	2 (0.1)	11 (0.8)	5 (0.4)	14 (1.0)	3 (0.2)	7 (0.5)	4 (0.3)	12 (0.8)
Education	381 (26.5)	388 (26.9)	389 (27.0)	411 (28.5)	4 (0.3)	3 (0.2)	5 (0.4)	6 (0.4)
Recreational Screen Use	95 (6.6)	141 (9.8)	62 (4.3)	88 (6.1)	274 (19.0)	396 (27.5)	210 (14.6)	227 (15.8)
Quiet Time	12 (0.8)	7 (0.5)	15 (1.0)	9 (0.6)	32 (2.2)	14 (1.0)	44 (3.1)	53 (3.7)
Sleep	679 (47.2)	643 (44.6)	694 (48.2)	641 (44.5)	792 (55)	716 (49.7)	819 (56.9)	773 (53.7)
Passive Transport	45 (3.1)	58 (4.0)	50 (3.5)	69 (4.8)	45 (3.1)	39 (2.7)	52 (3.6)	42 (2.9)
Sleep schedule, mean (SD)								
Bedtime (24Hour:Min)	21:14 (0:52)	21:54 (0:53)	21:12 (0:46)	21:57 (0:53)	21:35 (1:05)	22:27 (1:09)	21:40 (1:03)	22:23 (1:16)
Wake-up time (24Hour:Min)	6:57 (0:35)	6:49 (0:36)	7:00 (0:35)	6:49 (0:32)	7:18 (1:01)	7:35 (1:57)	7:25 (1:00)	7:56 (1:06)

Note. Analytical sample included participants who provided time-use diaries of the same day types ([a] school-day; [b] non-school day) at both time points. Data presented as [c] arithmetic means (standard deviation), which is calculated as the average minutes spent in each domain, linearly adjusted to

collectively sum to 1440 min (24 h); and [d] compositional means (percentage of a 24-hour day), which is calculated as the geometric mean of each domain, linearly adjusted to collectively sum to 1440 min (24 h).

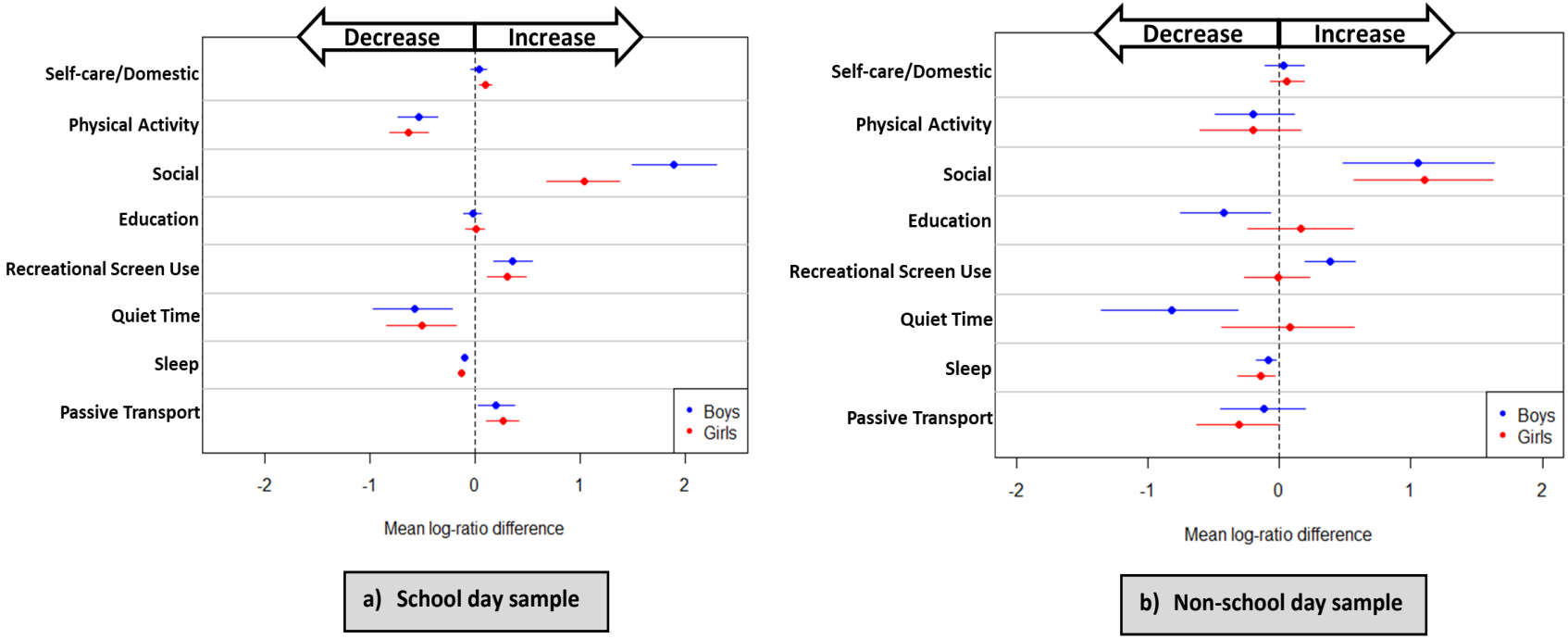

Figure 6.2 Bootstrapped mean and 95% confidence interval for the log-ratio differences of compositional means of activity domains between primary (T1) and secondary school (T2) for the a) school day and b) non-school day samples

Note. The log-ratio difference was calculated by using the compositional means of a activity domain at T2 as the numerator and its compositional means at T1 as the denominator (i.e. *ln*[T2/T1]). A positive value of the log-ratio difference* indicates an increase in time spent on this domain from T1 to T2, and vice versa. The change within each activity domain is considered significant if its confidence interval does not cross the zero vertical line. *(*A log-ratio difference of 0.35 for recreational screen use in boys (Figure 1a) indicates that the time allocated to this domain was increased by 35% from T1 to T2.)*

In relation to sleep schedule (Table 6.3), school-day sample reported later bedtimes but earlier wake-up times T2, whereas non-school day sample reported both later bedtimes and wake-up times at T2.

As shown in Table 6.4, boys reported significantly lower levels of psychosocial problems (internalising problems, externalising problems and total difficulties scores; all p<0.0001), but also decreased prosocial behaviour (p=0.003) from T1 to T2. Among girls, significant decreases were only observed in internalising problems (p<0.0001) and total difficulties scores (p<0.0001).

Table 6.4 Changes in psychosocial health outcomes from primary (T1) to secondary school (T2) time points

Psychosocial health outcomes	Boys (n=426)			Girls (n=483)		
	T1	T2	p-value	T1	T2	p-value
Internalising problems[a]	4.6 (3.4)	3.6 (3.2)	<0.0001	4.7 (3.4)	3.8 (3.0)	<0.0001
Externalising problems[a]	6.1 (3.8)	5.3 (3.5)	<0.0001	4.8 (3.1)	4.6 (3.2)	0.302
Total difficulties[b]	10.7 (6.3)	9.0 (5.8)	<0.0001	9.5 (5.7)	8.4 (5.2)	<0.0001
Prosocial behaviour[c]	7.7 (1.8)	7.4 (1.8)	0.003	8.4 (1.4)	8.4 (1.4)	0.383

Data presented as mean (standard deviation). The change in score from T1 to T2 was tested using a paired sample t-test. Score range: [a] 0-20; [b] 0-40; [c] 0-10.

Table 6.5 presents the compositional regression models for the associations between changes in the movement behaviour composition and changes in psychosocial health. Among boys, the change in overall movement behaviour composition was significantly associated with the change in prosocial behaviour (p=0.017), but not with other outcomes. The observed association with prosocial behaviour was mainly driven by its associations with changes in time spent in Social (B_{ilr}=-0.06, p=0.014) and Recreational Screen Use domains (B_{ilr}=-0.17, p=0.003) (relative to time spent in the remaining domains) (Table 6.6). For example, using the compositional means at T1 (Appendix 6.5) as the starting durations, a reallocation of 30 min from the remaining domains to the Social or Recreational Screen Use domain was associated with a decrease of 0.16 (95% confidence interval (CI)=-0.29, -0.03; effect size=0.09) and 0.03

units (95%CI=-0.05, -0.01; effect size=0.02) in prosocial behaviour at follow-up, respectively. There were no significant associations between the change in the overall movement behaviour composition and changes in any of the psychosocial health outcomes among girls (Table 6.5).

Table 6.5 Associations between changes in 24-hour domain-specific movement behaviour composition and changes in psychosocial health outcomes

Changes in psychosocial health outcome	Association with the change in overall movement behaviour composition			
	Boys (n=426)		Girls (n=483)	
	Sum^2	p-value	Sum^2	p-value
Internalising problems	74.1	0.099	74.7	0.093
Externalising problems	85.4	0.120	26.7	0.818
Total difficulties	189.9	0.161	134.6	0.390
Prosocial behaviour	45.9	0.017	9.1	0.607

All models adjusted for family socio-economic position index, main language spoken at home (English vs. non-English), body mass index z-score (T1), change in pubertal progression score (T2 minus T1), change in general health rating (T2 minus T1), being bullied at school in the last year (Yes vs. No) (T2), change in school environment (Yes vs. No) (T2), and corresponding health outcome at T1.

Table 6.6 Full regression model for the associations between changes in 24-hour domain-specific movement behaviour composition and changes in prosocial behaviour among boys

Changes in domains	Changes in prosocial behaviour	
	β_{ilr}	p
Self-care/Domestic	0.13	0.231
Physical activity	-0.06	0.259
Social	-0.06	0.014
Education	0.03	0.667
Recreational screen use	-0.17	0.003
Quiet time	0.01	0.624
Sleep	0.07	0.646
Passive transport	0.05	0.326

Note. β_{ilr} represents isometric log-ratio (*ilr*) regression coefficient of the specific behaviour relative to all remaining behaviours of the composition. The model is adjusted for family socio-economic position index, main language spoken at home (English vs. non-English), body mass index z-score (T1), change in pubertal progression score (T2 minus T1), change in general health rating (T2 minus T1), being bullied at school in the last year (Yes vs. No) (T2), change in school environment (Yes vs. No) (T2), and prosocial behaviour scores at T1.

6.4 Discussion

This study explored changes in the 24-hour domain-specific movement behaviour composition and their associations with changes in psychosocial health during the transition from primary to secondary school. Overall, the 24-hour movement behaviour composition changed significantly across the school transition period, with more prominent changes observed in the school day sample than in the non-school day sample. Across the two samples, both boys and girls reported spending more time in social activities and less time in sleep. Further, change in the overall movement behaviour composition was not moderated by the change in school environment. In relation to the changes in psychosocial health, increased time spent in the social activities and recreational screen use (relative to other activity domains) were associated with decreased prosocial behaviour in boys at the secondary school period; however, the associations were small in magnitude and must be interpreted with caution. No associations were identified for any of the other psychosocial health outcomes, particularly among girls.

Consistent with previous research (Chong et al. 2021; Chong et al. 2020; Pearson et al. 2017), this study revealed a drastic change in children's time-use patterns across different activity domains as they moved from primary to secondary school. In particular, participants in the school day sample reported spending significantly more time in recreational screen use and passive travel and less time in physical activity, indicating a shift towards an inactive lifestyle on school days during this school transition period (Chong et al. 2021). While changes in movement behaviour composition were more prominent in the school day sample than in the non-school day sample, both samples consistently reported spending more time in social activities and less time in sleep. The increase in social time may be related to social developmental changes associated with the transition to adolescence, which is often characterised by heightened sensitivity to social stimuli and the increased need for peer interactions (Orben, Tomova & Blakemore 2020). On the other hand, the decrease in sleep time was primarily due to later bedtimes (with a smaller change in wake-up time) during secondary

compared to primary school, which may be partly explained by developmental changes in circadian rhythms that occur in response to the onset of puberty (Crowley et al. 2018); or other external factors such as increased recreational screen use (Hale & Guan 2015) and academic pressure (Evans-Whipp & Gasser 2019). Taken together, these findings demonstrate the need for a whole-day intervention approach considering the trade-off between activity domains (rather than a single-behaviour approach) to assist children in developing and/or maintaining a healthy and balanced movement behaviour composition during this key transition. The finding that behavioural changes observed in the school day sample were of a larger magnitude compared to the non-school day sample during this transition period highlights the importance of targeted future interventions to incorporate strategies addressing the school day's routine (e.g., promoting active school transport, delaying school start time) (Chaput 2019; Villa-González et al. 2018).

This study found that the sex-related differences in behavioural changes were more apparent for the non-school day sample compared to the school day sample. One possible explanation is that children are often exposed to a 'less-structured' environment (i.e., less regulations or restrictions) on the non-school days, where they are afforded greater autonomy over their time-use patterns (Brazendale et al. 2017). On the other hand, school days are typically comprised of a pre-planned, restrictive and compulsory routine that are likely the same for the majority of children (Brazendale et al. 2017), which might have reduced the variability of changes in behaviours between boys and girls. It was observed that the change in the movement behaviour composition was not moderated by the change in school environment. This finding contradicts previous research that found greater changes in daytime activity patterns (e.g., less likely to engage in active school transport, longer duration of leisure screen time) among children who moved to a new secondary school compared to those who did not change school (Marks et al. 2015). The differences in measurement types (i.e., daily behaviour composition vs. participation in specific types of activities) and analytical approach used are likely the main explanations for

these inconsistent findings. It could also be that other unmeasured factors, such as the school and neighbourhood environment characteristics (Pate et al. 2019; Morton et al. 2016b; De Meester et al. 2014), moderated or mediated the impact of changing school environment on children's movement behaviour patterns during this school transition period.

With respect to children's psychosocial health profiles, both boys and girls reported a lower level of total psychosocial difficulties after the transition into secondary school. This finding is in contrast to those of an Australian study that used the same assessment tool (SDQ) and observed increased levels of psychosocial problems over the school transition period (Lester & Cross 2015). These inconsistent findings may be related to children's expectations and/or experiences of the school transition; individuals who express more worries about the transition or experience a poorer transition appear to have greater levels of psychological difficulties as they progress through secondary school (Evans, Borriello & Field 2018; Waters et al. 2012). In this study, only a small proportion of participants (13.4%) who moved to a new secondary school at T2 reported experiencing some difficulties with changing schools during this transition period. This suggests the possibility that the majority of study sample had a positive school transition experience, which has been linked to better psychosocial health outcomes post-transition (Waters et al. 2012). Interestingly, a concurrent decrease in prosocial behaviour was observed in boys, but not in girls, during this school transition period. This finding aligns with previously observed age-related trends in prosocial behaviour, which appeared to decline more rapidly among boys than girls during early- to mid-adolescence (Carlo et al. 2007). The decrease in boys' prosocial behaviour could be explained by concurrent changes in their empathic ability associated with pubertal development (Masten et al. 2013), or other factors such as increased socialisation pressures and being more self-focused during this time period (Carlo et al. 2007).

This study did not find consistent associations between the 24-hour movement behaviour composition and psychosocial health during this school transition period. Only one of the four outcomes examined (i.e., prosocial behaviour) was related to the change in movement behaviour composition in boys and none were identified in girls. The lack of observed associations in the present study may be partly explained by the discrepancy in the reference period between time-use diaries (the day before interview) and psychosocial health data (the six-month period before the interview). Further, the change in movement behaviour composition was computed using data from a single day time-use diary at each time point, which may have introduced measurement bias into the analysis, limiting the ability to detect meaningful associations with changes in psychosocial health. However, it is possible that movement behaviours may have differential impacts across psychosocial health dimensions. Similar findings were reported in a cross-sectional study of primary school children, which found a specific association between the accelerometer-measured movement behaviour composition and prosocial behaviour, but not other SDQ outcomes (Fairclough et al. 2021). Additional research using multiple days of behavioural measures and a diverse set of psychosocial health outcomes is warranted to confirm these findings.

Relative to other activity domains, increased time spent in social activities and recreational screen use were found to be associated with decreased prosocial behaviour among boys. It is important to acknowledge, however, that the magnitude of the observed associations were small and may not be meaningful in terms of their clinical and practical significance. Furthermore, the negative association observed with time spent in social activities (e.g., participation in non-active club activities, attending community or school event) does not necessarily imply that social time *per se* is negatively related to prosocial behaviour. Due to the compositional nature of time-use data (Dumuid et al. 2018; Chastin et al. 2015), the time allocated to social activities could only be increased by taking the same amount of time away from one or more of the other activities that make up the 24-hour composition. This means that children who increased their

participation in social activities would have to reduce time spent in at least one other activity that may be beneficial for prosocial behaviours (e.g., physical activity). In other words, the negative association of social time with prosocial behaviour in boys may be explained by the displacement of time from other health-promoting activities rather than the time spent in social activities per se. It is worth noting that this study did not examine the nature or context of the social activities performed (e.g., the presence of positive social interactions, exposure to bullying), which might have moderated the observed association between social time and prosocial behaviour.

The negative association between recreational screen use and prosocial behaviour in boys appears to be consistent with the existing evidence demonstrating the negative effects of excessive screen time on children's psychosocial health (Oswald et al. 2020; Hoare et al. 2016; Carson et al. 2016a). It has been proposed that the negative impact of screen time may be partly explained by the displacement of opportunities for social interactions or other protective behaviours (e.g., physical activity and sleep) (Sampasa-Kanyinga et al. 2020; Khouja et al. 2019), which is consistent with the interpretation of the compositional time-use data (i.e., time spent in one activity domain can only be increased by taking the same amount of time away from at least one of the remaining domains) as presented in this study. It is also possible that the negative effects of screen time are directly attributed to the content and context of screen use (e.g., social comparison or exposure to cyberbullying) (Sampasa-Kanyinga et al. 2020; Khouja et al. 2019). More recently, it was demonstrated that the types of screen use behaviours may moderate the impact of screen time on children's psychosocial outcomes (Sanders et al. 2020). In particular, greater time spent on interactive (e.g., playing computer games), social (e.g., online chatting/instant messaging), and other forms of screen use (e.g., general internet browsing), but not educational or passive screen time (e.g., television viewing), were associated with poorer prosocial behaviour (Sanders et al. 2020). As such, both the duration and type of screen use behaviours should be considered when developing intervention strategies to facilitate

prosocial behaviour development in boys during this school transition period. It is important to acknowledge, however, that the magnitude of the observed associations were small and may not be meaningful in terms of their clinical and practical significance.

This was the first known study to report the longitudinal changes in 24-hour movement behaviours and their combined associations with changes in psychosocial health during the transition from primary to secondary school. Strengths of this study include: 1) the large sample size; 2) the analysis of time-use diary data, which enabled the quantification of time spent in different domains of movement behaviours across the whole day; and 3) the use of a CoDA approach to account for the co-dependent nature of time-use data. Nonetheless, as with all self-report measurements, the self-reported data on movement behaviours and psychosocial health are subject to some degree of reporting biases. Furthermore, the discrepancy in time periods for the completion of time-use diary and SDQ assessment may have confounded the associations between movement behaviours and psychosocial health. Another limitation of this study was that only a single day of time-use data were available for the analysis at each time point, which may not accurately reflect children's habitual movement behaviour patterns. Additionally, the present analysis focused on the association between the change in movement behaviours and the change in psychosocial health outcomes, precluding the direction/temporal sequence of the association to be determined. It should also be noted that the time-use diary data were collected over a decade ago (2010-2012), and it is plausible that children's movement behaviour patterns may have changed considerably since then due to the rising availability and accessibility of portable electronic devices (i.e., more screen time), and more recently, the impact of COVID-19 pandemic (Paterson et al. 2021). Finally, data used in this study were drawn from an Australian population survey; they may not generalise to other countries with a different education system.

6.5 Conclusion

This study revealed significant changes in children's 24-hour domain-specific movement behaviour composition as they transition from primary to secondary school. There were, however, a lack of consistent associations between the change in movement behaviour composition and changes in psychosocial health during this school transition period. Further longitudinal research is needed to better understand the potential role of movement behaviours in fostering children's psychosocial development during this key transition, and to explore whether the associations vary between dimensions of psychosocial health and demographic subgroups.

6.6 References

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Chapter 7: Cross-sectional and longitudinal associations between 24-hour movement behaviours, recreational screen use and psychosocial health outcomes in children: a compositional data analysis approach

Chapter 5 revealed that there was an unfavourable change in children's 24-hour movement behaviour composition (i.e., increased sedentary time and decreased physical activity and sleep duration) during the primary to secondary school transition period, especially on weekdays. Chapter 6 demonstrated that changes in the movement behaviour composition, specifically the time spent in social and recreational screen use domains, were associated with changes in prosocial behaviour in boys. Considering the high prevalence of recreational screen use in this population and the potential impacts on psychosocial health (as described in Chapter 2), this chapter determined whether the 24-hour movement behaviour composition and recreational screen use contributed independently and uniquely to children's psychosocial health both cross-sectionally and longitudinally. The following research question was investigated in this chapter:

Research Question 2:

Are 24-hour movement behaviours associated with children's psychosocial health during the transition from primary to secondary school?

Sub-research question:

2.2 Are the 24-hour movement behaviour composition and recreational screen use independently associated with children's psychosocial health, both cross-sectionally and longitudinally?

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7.1 Background

Psychosocial health problems are increasingly common among children and adolescents, with the worldwide-pooled prevalence of mental disorders estimated to be 13.4% (Polanczyk et al. 2015). Anxiety, behavioural and depressive disorders are among the most frequently reported mental health conditions (Polanczyk et al. 2015; Merikangas, Nakamura & Kessler 2009), accounting for 16% of the global burden of disease and injury among adolescents (World Health Organization 2020). Most mental disorders are reported to develop during childhood or adolescence (Kessler et al. 2007), which is likely to have a profound impact on other health and developmental outcomes (e.g., educational underachievement, substance use and abuse) (Patel et al. 2007). It is therefore important to identify modifiable determinants of psychosocial health for early prevention and intervention.

Physical activity (Poitras et al. 2016), sedentary behaviour (Carson et al. 2016a), and sleep (Chaput et al. 2016), collectively known as 24-hour movement behaviours (Tremblay et al. 2016), have been shown to be independently associated with various psychosocial health outcomes (e.g., mental health, anxiety, psychological distress, behavioural conduct) in children and adolescents. However, because the times spent engaging in these behaviours are mutually exclusive and exhaustive components of a 24-hour day (i.e., changing time spent in one behaviour requires compensatory changes in at least one other behaviour), their effects on health should be analysed and interpreted relative to each other rather than in isolation (Pedišić, Dumuid & Olds 2017; Chastin et al. 2015). This can be done using compositional data analysis (CoDA), a statistical approach designed to handle compositional data that convey relative information (i.e., only the ratios between the parts of a composition are informative), therefore making it suitable for analysis of time-use data (Dumuid et al. 2020; Dumuid et al. 2018a; Chastin et al. 2015). To the best of the candidate's knowledge, only two cross-sectional studies have examined the association between the full 24-hour movement behaviour composition (i.e., time spent in sleep, sedentary time, light-intensity physical activity (LPA) and moderate- to

vigorous-intensity physical activity (MVPA)) and psychosocial health outcomes in school-aged children and adolescents using a CoDA approach (Fairclough et al. 2021; Carson et al. 2016b). The findings from these studies suggest that the overall movement behaviour composition is important for emotional and behavioural development. Given the paucity of research in this area, more studies, particularly of longitudinal design, are needed to better understand the collective and relative associations between 24-hour movement behaviours and psychosocial health among children and adolescents.

There is substantial evidence that high levels of recreational screen use (e.g., television watching, playing computer/video) can have a detrimental effect on children's and adolescents' psychosocial health (Oswald et al. 2020; Sanders et al. 2019; Stiglic & Viner 2019; Liu, Wu & Yao 2016). However, it remains largely unknown whether the effects of screen use are explained by the content/context of the screen viewing or the displacement of opportunities for other health-promoting activities (e.g., physical activity, social activities) (Oswald et al. 2020; Stiglic & Viner 2019). While it has been proposed that the negative effects of sedentary behaviour may be specific to the engagement in screen-based sedentary activities (Suchert, Hanewinkel & Isensee 2015a), there remains a lack of evidence justifying whether total sedentary time (i.e., time spent in all sedentary activities) or specific types of sedentary behaviour are more strongly related to psychosocial health indicators (Fairclough et al. 2021). Most of the published studies on the psychosocial health effects of screen time did not include newer forms of screen technologies (e.g., tablets and smartphones) (Oswald et al. 2020), nor did they account for the confounding influence of time spent in other movement behaviours (i.e., physical activity and sleep) (Oswald et al. 2020; Sanders et al. 2019; Liu, Wu & Yao 2016).

Recreational screen use is a highly prevalent form of sedentary behaviour among children and adolescents worldwide, with a significant proportion (38%-76%) not meeting the current recreational screen time recommendations, i.e., no more than 2 h/day (Bang et al. 2020; Roman-

Viñas et al. 2016). In addition, excessive screen use is likely to have a negative impact on other movement behaviours that have also been linked to psychosocial health (e.g., shorter sleep duration) (Stiglic & Viner 2019; Twenge, Hisler & Krizan 2019). Thus, it is important to determine whether the distribution of time spent in 24-hour movement behaviours and recreational screen use contribute independently and uniquely to psychosocial health outcomes. This information has the potential to inform the development of future movement behaviour intervention strategies and guidelines for the promotion of healthy psychosocial development in children and adolescents.

The purpose of this study was to examine the cross-sectional and longitudinal associations between 24-hour movement behaviour composition, recreational screen use and psychosocial health outcomes in a sample of school children. Specifically, this study sought to determine: 1) if the associations between movement behaviour composition and psychosocial health outcomes were independent of recreational screen use; and 2) if recreational screen use was associated with psychosocial health outcomes independent of the movement behaviour composition. We hypothesised that the movement behaviour composition and recreational screen use would be independently associated with children's psychosocial health outcomes in both cross-sectional and longitudinal analyses.

7.2 Methods

7.2.1 Study design and participants

Data were drawn from a longitudinal study that followed children transitioning from primary school (Year-6; aged 10-12y) to secondary school (Year-7; aged 11-13y). A convenience sample of government and independent schools (n=73) that were located within a 400 kilometres radius of the city of Wollongong in New South Wales, Australia were approached to participate in the study between July 2017 and December 2018. Information sheets and consent forms were sent home with all Year-6 students at the consenting schools to seek parental/legal

guardian consent for their participation in the study. At follow-up time points, parents/legal guardians were contacted via a passive consent form (for children who had stayed at the same school) or a new active consent form (for children who had moved to a new school) delivered to their home address or via email to seek their permission for the child to continue participating in the study. Baseline data were collected between April 2018 and August 2019, with follow-ups conducted an average of six months (range 4-9 months) (Follow-up 1: October 2018-March 2020) and 12 months (range 11-16 months) (Follow-up 2: April 2019-November 2019) after baseline using a standardised data collection protocol (i.e., 24-hour accelerometer wearing, completing a questionnaire and anthropometric measurements). The study was terminated in April 2020 as the University officially suspended all face-to-face data collection due to COVID-19. The conduct of this study was reviewed and approved by the Human Research Ethics Committee of the University of Wollongong (HREC 2017/255) and the New South Wales Department of Education (SERAP No. 2018365).

The current study analysed data collected at two time points. For the cross-sectional analysis, the analytical sample included participants who had valid accelerometry, recreational screen use and psychosocial health data at baseline (Year-6; referred to hereafter as T1). For the longitudinal analysis, the analytical sample comprised of participants who had valid accelerometry and recreational screen use data at T1 and psychosocial health data at one follow-up time point during the secondary school period (Year-7; referred to hereafter as T2). Due to the variation at the baseline time frames between schools, some participants had only one data point for T2, while others had two data points for T2. In the latter cases, the data point with the longest follow-up time was included to strengthen the robustness of the longitudinal results.

7.2.2 Measures

i. Accelerometer-measured 24-hour movement behaviours

Time spent in sleep, sedentary time, LPA and MVPA was assessed using a wrist-worn GENEActiv accelerometer (ActivInsights Ltd., Cambridgeshire, UK) on the non-dominant wrist for six consecutive days (24 h/day). The GENEActiv accelerometer has been validated for the assessment of sedentary behaviour (van Loo et al. 2017) and MVPA (van Loo et al. 2018) in children. Accelerometer data (sampled at 75 Hz) were downloaded using GENEActiv PC software version 3.2 (ActivInsights Ltd., Cambridgeshire, UK) and saved in raw format as binary files. The data files were then processed in R using the GGIR package (version 1.10-7) (Migueles et al. 2019), which auto-calibrated the raw triaxial accelerometer signals (van Hees et al. 2014) and computed the Euclidean Norm Minus One (ENMO) metric (i.e., gravity-corrected vector magnitude units) (van Hees et al. 2013). ENMO values were averaged over 5-second epochs and expressed in milli-gravitational units (m*g*). Accelerometer non-wear time was estimated based on the standard deviation and value range of each accelerometer axis, calculated over 60-min windows with 15-min increments (van Hees et al. 2013). For each 15-min period detected as non-wear time over the valid wearing days, missing data were imputed using the mean values calculated from valid data at the same time points on other days (Migueles et al. 2019). A sleep detection algorithm (based on the distribution of change in arm angle) developed by van Hees and colleagues (2018) was applied to identify the sleep period time window for the estimation of sleep duration (including awakening periods). This algorithm has been applied previously in wrist-worn accelerometry studies involving children (Fairclough et al. 2021; Antczak et al. 2020; Fairclough et al. 2017). Waking time data were further categorised as sedentary time (ENMO<52 m*g*), LPA (ENMO 52-191 m*g*) or MVPA (ENMO≥192 m*g*) using validated acceleration intensity thresholds (Hurter et al. 2018; Hildebrand et al. 2014).

To be included in the analysis, participants were required to have at least three valid days of accelerometer data (i.e., at least 16 h/day of wear time; including one weekend day) (Fairclough et al. 2017). Any days with ≤200 min of sleep duration or ≥1000 min of sedentary time were considered invalid and were excluded from the analysis (Dumuid et al. 2019). The average time spent in each behaviour was weighted at 5:2 for weekdays and weekend days.

ii. Recreational screen use

Participants were asked to report the amount of time spent engaging in a range of sedentary and screen-based activities (i.e., while sitting) on each weekday (during out-of-school hours only) and weekend day during a typical school week. These activities were adapted from the revised version of the Adolescent Sedentary Activity Questionnaire (ASAQ) (Hardy et al. 2016); with an additional item assessing the use of screen devices for social purposes (e.g., text/instant messaging, using social networking sites) to reflect current trends in children's screen media use. In the current study, daily recreational screen time was calculated by taking a weighted average of total time spent in five screen-based sedentary activities (i.e., watching television, using a computer/laptop for entertainment, using a smartphone/tablet for entertainment, playing computer/video games and using screen devices for social purposes) on weekdays and weekend days: (average of weekdays*5+average of weekends*2)/7. For analysis purposes, participants were classified into low (≤2 h/day) or high (>2 h/day) levels of recreational screen use based on the Australian sedentary recreational screen time recommendation (Australian Government Department of Health 2019).

iii. Psychosocial health measures

Psychosocial health was assessed using the self-report version of the Strengths and Difficulties Questionnaire (SDQ) (Goodman 1997) and the Kessler's Psychological Distress Scale (K-10) (Kessler et al. 2002). These questionnaires have been used in the Australian population surveys

(Sanders et al. 2019; Thomas et al. 2017), indicating the appropriateness and acceptability of the questionnaires among Australian children and adolescents.

The SDQ (Goodman 1997) consists of 25 items equally divided across five subscales assessing emotional and behavioural problems in children: emotional symptoms, conduct problems, hyperactivity, peer problems and prosocial behaviours. It has demonstrated acceptable construct validity (Van Roy, Veenstra & Clench-Aas 2008) and sensitivity to detect change in mental health functioning among children and adolescents (Ford et al. 2007), making it appropriate for longitudinal studies. In this study, the self-report version of the SDQ was used where participants were asked to indicate the degree to which each item applies to them over the last six months using a 3-point Likert scale: 'not true', 'somewhat true', or 'certainly true'. 'Somewhat true' is always scored as 1, but the scoring of 'not true' and 'certainly true' varies across items (0 or 2). The scores for each item were calculated and subsequently used to compute three subscale scores for assessing internalising problems (the sum of the emotional symptoms and peer problems subscales; range 0-20), externalising problems (the sum of the conduct problems and hyperactivity subscales; range 0-20), and prosocial behaviour (range 0-10). This three-subscale SDQ model has been recommended for use in studies involving low-risk or general population samples (Goodman, Lamping & Ploubidis 2010). In the current study, the internal consistency (Cronbach's alpha, α) for the three subscales (internalising problems=0.69; externalising problems=0.74; prosocial behaviours=0.64) were acceptable. A total difficulties score was also computed by summing the scores of the internalising problems and externalising problems subscale (range 0-40). The calculated scores for the four main outcome variables (internalising problems, externalising problems, total difficulties scores and prosocial behaviour) were further categorised as 'close to average', 'slightly raised', 'high' or 'very high' based on the recommended four-band classification (Dray et al. 2016).

The K-10 scale (Kessler et al. 2002) is a 10-item self-report questionnaire developed for assessing non-specific psychological distress based on the level of anxiety and depressive symptoms experienced during the past 4-week period. Participants were asked to indicate the degree to which each item applied to them using a 5-point Likert scale (1='none of the time', 2='a little of the time', 3='some of the time', 4='most of the time', 5='all of the time'). A total score was calculated by summing the scores of all 10 items (range 10-50), with higher scores representing higher levels of psychological distress. The calculated scores were further categories as 'low', 'moderate', 'high' or 'very high' using the recommended cut-points (Australian Bureau of Statistics 2012). The K-10 scale has demonstrated sufficient unidimensionality (Smout 2019) and acceptable internal consistency (Cronbach's alpha, α=0.70–0.90) (Hoare et al. 2017; Thomas et al. 2017) among Australian children and adolescents aged 11-17 years. In the current study, the internal consistency of this scale was high (α=0.84).

iv. Control variables

The following variables were included as covariates in the analyses: socio-demographic characteristics (age, sex and socio-economic status), body mass index z-score (BAZ), pubertal progression and experience with transition from primary to secondary school. These variables were selected due to their associations with movement behaviours (Rollo, Antsygina & Tremblay 2020) and/or psychosocial health outcomes (Mensah et al. 2013; Waters et al. 2012) in children and adolescents.

Socio-demographic information (sex, date of birth and home postcode) was provided by the parents/legal guardians on the consent form. A standardised measure of socio-economic status (Socio-Economic Indexes for Areas Index of Relative Socio-Economic Disadvantage; SEIFA IRSD) (Australian Bureau of Statistics 2018) was derived from the home postcode provided, with higher values indicating relatively less disadvantaged. Body weight was measured using a

digital scale (Model 874; SECA, Hamburg, Germany), and height was measured using a portable stadiometer (Model 217; SECA, Hamburg, Germany). BAZ was calculated using AnthroPlus software version 1.0.4 (World Health Organization, Geneva, Switzerland) based on the 2007 World Health Organization growth reference (de Onis et al. 2007). Pubertal progression was assessed using an average score derived from three general (i.e., growth spurt, body hair growth, skin changes) and two sex-specific (boys: facial hair growth and voice changes; girls: breast development and the onset of menarche) indicators of puberty (Carskadon & Acebo 1993). Each indicator was scored on a 4-point Likert scale from 1 'has not started yet' (or 'no' for menarche item) to 4 'seems completed' (or 'yes' for menarche item). A change in pubertal progression score was also computed (T2 estimates minus T1 estimates) for use in the longitudinal analyses. At T2, participants were asked to rate their experiences in transitioning to secondary school using a four-level Likert scale: 'difficult', 'somewhat difficult', 'somewhat easy' or 'easy' (adapted from Waters et al. (2012)) These data were further categorised as having a difficult (combined 'difficult' and 'somewhat difficult' responses) or easy (combined 'somewhat easy' and 'easy' responses) transition experience and were included in the longitudinal analyses.

7.2.3 Statistical analyses

Standard statistical analyses were performed in IBM SPSS Statistics for Windows (version 26; IBM Corp., Armonk, New York). Descriptive statistics (mean, standard deviation, frequency and percentage) were calculated to summarise participant characteristics. Differences between participants included and excluded from the cross-sectional or longitudinal analyses were analysed using independent t-tests. Changes in participant characteristics from T1 to T2 were analysed using paired sample t-tests or McNemar-Bowker's tests.

Compositional data analyses were performed in R (version 3.6.2; R Foundation for Statistical Computing, Vienna, Austria) using the 'compositions' (version 2.0.0) (van den Boogaart &

Tolosana-Delgado 2008), 'lme4' (version 1.1-23) (Bates et al. 2015) and 'lmerTest' (version 3.1-3) (Kuznetsova, Brockhoff & Christensen 2017) packages. Compositional descriptive statistics, including compositional mean (measure of central tendency) and pairwise log-ratio variation matrix (measure of dispersion/variability), were used to describe the daily composition of 24-hour movement behaviours (Chastin et al. 2015). The four-part movement behaviour composition was expressed as four specific sets of three isometric log-ratio (*ilr*) coordinates for statistical analyses, each of which included a different behaviour (either sleep, sedentary time, LPA or MVPA) relative to all remaining behaviours as the first *ilr* (Dumuid et al. 2018a; Chastin et al. 2015). Association analyses were conducted using the linear mixed models to account for the random effect of school clustering (school site as random intercept). For cross-sectional analyses, four models were constructed for each T1 psychosocial health outcome (as the dependent variable); each model included one of the four sets of T1 movement behaviour *ilrs* created and recreational screen use (low vs. high levels) as the explanatory variables. This was done so that each model analysed the association of one specific behaviour relative to all remaining behaviours.

All cross-sectional models were adjusted for socio-demographic characteristics, BAZ and pubertal progression score. The longitudinal analyses were conducted using a similar approach by including T2 psychosocial health outcome as the dependent variable, and the sets of T1 movement behaviour *ilrs* and recreational screen use as the explanatory variables. All longitudinal models were adjusted for socio-demographic characteristics, BAZ (T1), change in pubertal progression score, school transition experiences and the corresponding T1 psychosocial health outcome. All models were checked for linearity, normality and homoscedasticity of residuals, and outliers to ensure assumptions were not violated.

The ANOVA table of the model fit was checked for the statistical significance of the associations between the set of movement behaviour *ilrs* (representing the daily movement

behaviour composition) and recreational screen use with each psychosocial health outcome. If a significant association ($p<0.05$) was observed for the set of movement behaviour *ilrs*, the regression coefficients and statistical significance of the first *ilr* from the four models were examined to determine the health association of each behaviour relative to all remaining behaviours.

7.3 Results

A total of 426 Year-6 children from 12 participating schools were invited to participate in this study, of which 135 (59 boys, 76 girls; mean age=11.7y) (response rate=31.7%) provided written parental consent and verbal assent and completed the study protocol at T1 (Figure 7.1). Of these, 121 (89.6%) completed at least one of the follow-up assessments. Eight participants did not provide valid accelerometry data at T1, leaving a sample size of 127 (94.1%) for the cross-sectional analysis. Of this sample, 88 (69.3%) also provided psychosocial health data at T2 (mean follow-up duration=12±2 months) and were included in the longitudinal analysis. The longitudinal analytical sample was older ($p=0.015$) and of a higher socio-economic status ($p<0.0001$) than the drop-out sample (Appendix 7.1).

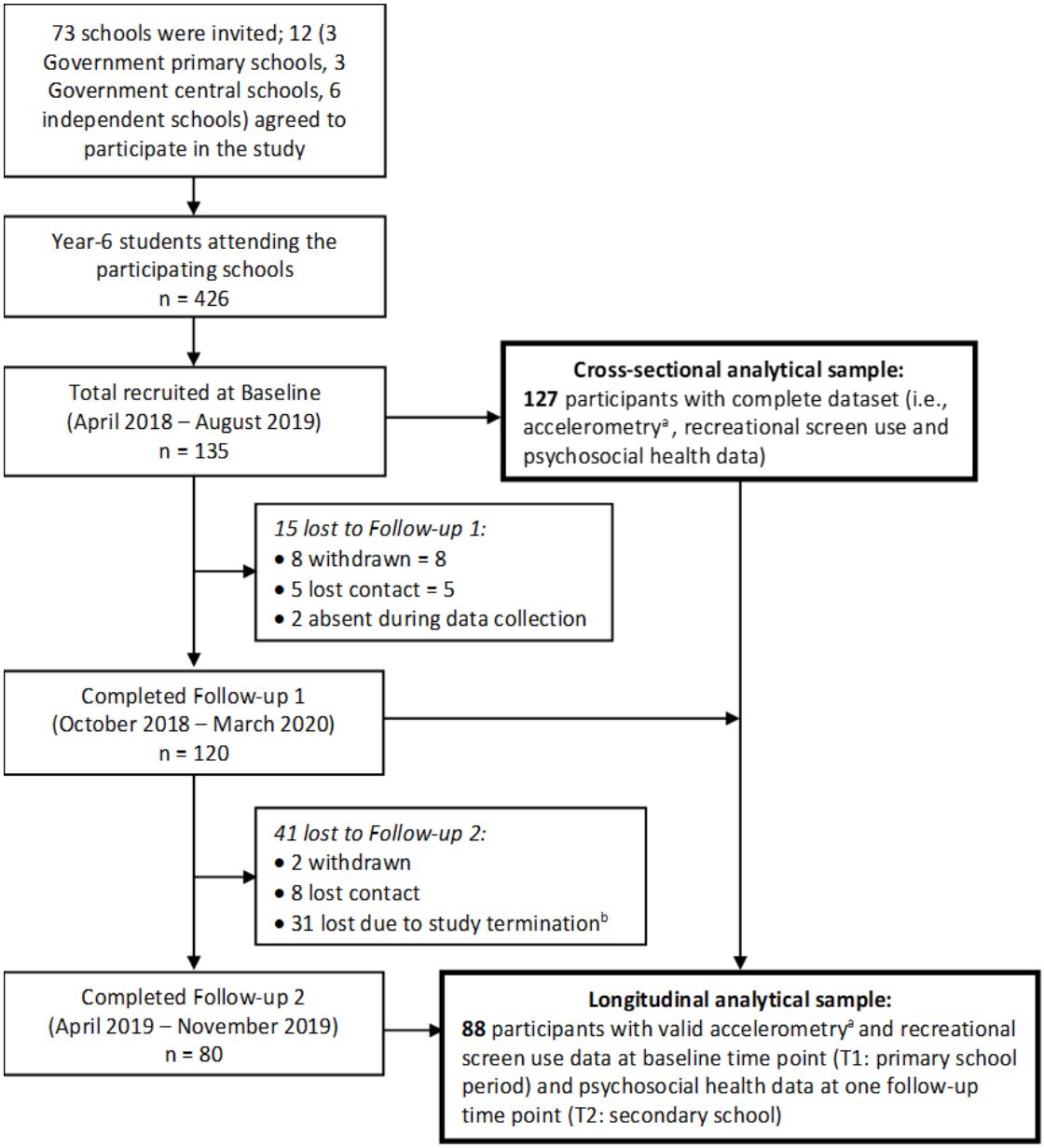

Figure 7.1 Flowchart of participants through the study

[a] Provided at least three valid days of accelerometer data (i.e., at least 16 h of wear time per day, including one weekend day).
[b] Study was terminated in April 2020 as the University officially suspended all face-to-face data collection due to COVID-19.

The descriptive characteristics of the cross-sectional and longitudinal samples are summarised in Table 7.1. The average daily movement behaviour compositions were similar between the two samples at T1, with the largest proportion of 24-hour period spent sedentary (~42%), followed by sleep (~38%), LPA (~15%) and then MVPA (~5%). Most participants (>60%)

spent more than 2 h/day on recreational screen use. The pairwise log-ratio variances indicated that sleep and sedentary time had the highest co-dependence, whereas MVPA had the lowest co-dependence with the other three behaviours in both cross-sectional and longitudinal samples (Appendix 7.2).

Table 7.1 Characteristics of the analytical sample

Characteristics	Cross-sectional sample (n=127)	Longitudinal sample (n=88)		
		T1	T2	p-value[a]
Age (years)	11.7 (0.5)	11.8 (0.4)	12.8 (0.4)	
Sex, n (%) girls	73 (57.5)	52 (59.1)	-	
Socio-economic status (SEIFA IRSD)	987 (62)	1003 (44)	-	
BAZ[b]	0.44 (1.14)	0.41 (1.12)	0.44 (1.14)	0.439
Pubertal progression score	2.02 (0.55)	2.03 (0.55)	2.41 (0.64)	<0.0001
Psychosocial health				
Internalising problems	5.5 (3.4)	5.4 (3.4)	5.5 (3.7)	0.913
Externalising problems	6.6 (3.3)	6.7 (3.2)	6.6 (3.3)	0.903
Total difficulties scores	12.1 (5.8)	12.2 (5.7)	12.1 (5.7)	1.000
Prosocial behaviour	7.8 (1.8)	7.9 (1.9)	7.8 (1.6)	0.560
Psychological distress	21.5 (6.8)	21.2 (6.7)	21.7 (7.5)	0.434
Movement behaviour composition, min/day[c] (% of 24-hour)				
Arithmetic means (SD)				
Sleep	540 (42)	544 (42)	-	
SED	612 (72)	605 (66)	-	
LPA	215 (37)	218 (34)	-	
MVPA	73 (27)	73 (27)	-	
Compositional means (% of 24-hour)[d]				
Sleep	544 (37.8)	548 (38.0)	-	
SED	614 (42.6)	607 (42.2)	-	
LPA	213 (14.8)	217 (15.1)	-	
MVPA	69 (4.8)	68 (4.7)	-	
Recreational screen use, mins/day[c]	207 (131)	189 (124)	-	
High screen use (>2 h/day), n (%)[c]	86 (67.7)	56 (63.6)	-	

Data presented as mean (standard deviation) unless indicated.
[a] Examined using paired sample t-test.
[b] Missing data for one participant at T2.
[c] Data at T2 were not reported as they were out-of-scope for this study.
[d] Calculated as the geometric mean of each behaviour, linearly adjusted to collectively sum to 1440 min (24 h).
SEIFA=Socio-economic Indicators for Areas; IRSD=Index of Relative Social Disadvantage; BAZ=body mass index z-score; SED=sedentary time; LPA=light-intensity physical activity; MVPA=moderate- to vigorous-intensity physical activity.

More than half the participants had their SDQ subscale (internalising problems, externalising problems, prosocial behaviour) and total scores (total difficulties scores) in the 'close to

average' range, and had low/moderate levels of psychological distress, with no significant differences observed in the proportions between T1 and T2 (Table 7.2). Of the longitudinal sample, 4.5% (n=4) had changed schools since T1 and 36.4% (n=32) were reported to have experienced a difficult transition to secondary school.

Table 7.2 Classifications of psychosocial health status

Classifications[a]	Cross-sectional sample (n=127)	Longitudinal sample (n=88)		
		T1	T2	p-value[b]
Internalising problems				
Close to average (0 – 6)	82 (64.6)	58 (65.9)	59 (67.0)	0.766
Slightly raised (7 – 8)	18 (14.2)	14 (15.9)	9 (10.2)	
High (9)	5 (3.9)	3 (3.4)	8 (9.1)	
Very high (10 – 20)	22 (17.3)	13 (14.8)	12 (13.6)	
Externalising problems				
Close to average (0 – 8)	91 (71.7)	64 (72.7)	61 (69.3)	0.857
Slightly raised (9 – 10)	20 (15.7)	12 (13.6)	17 (19.3)	
High (11 – 12)	10 (7.9)	6 (6.8)	6 (6.8)	
Very high (13 – 20)	6 (4.7)	6 (6.8)	4 (4.5)	
Total difficulties scores				
Close to average (0 – 14)	86 (67.7)	62 (70.5)	59 (67.0)	0.762
Slightly raised (15 – 17)	16 (12.6)	10 (11.4)	11 (12.5)	
High (18 – 19)	7 (5.5)	5 (5.7)	7 (8.0)	
Very high (20 – 40)	18 (14.2)	11 (12.5)	11 (12.5)	
Prosocial behaviour				
Close to average (7 – 10)	94 (74.0)	66 (75.0)	69 (78.4)	0.679
Slightly raised (6)	16 (12.6)	11 (12.5)	8 (9.1)	
High (5)	10 (7.9)	7 (8.0)	9 (10.2)	
Very high (0 – 4)	7 (5.5)	4 (4.5)	2 (2.3)	
Psychological distress				
Low (10 – 15)	21 (16.5)	15 (17.0)	21 (23.9)	0.549
Moderate (16 – 21)	54 (42.5)	39 (44.3)	30 (34.1)	
High (22 – 29)	32 (25.2)	23 (26.1)	23 (26.1)	
Very high (30 – 50)	20 (15.7)	11 (12.5)	14 (15.9)	

Data presented as frequency (percentage).
[a] The recommended score range for each classification category is presented in brackets.
[b] Examined using McNemar-Bowker's test.

Table 7.3 presents the compositional regression models for the cross-sectional association analyses. The daily movement behaviour composition was significantly associated with internalising problems (p=0.021) and total difficulties scores (p=0.030), but not with other outcomes, after adjusting for recreational screen use levels and other covariates. Time spent in sleep relative to the other behaviours was negatively associated with internalising problems

(β_{ilr}=-6.85, p=0.017) and total difficulties scores (β_{ilr}=-13.31, p=0.006). Time spent sedentary relative to the other behaviours was positively associated with internalising problems (β_{ilr}=4.19, p=0.046). Time spent in LPA relative to the other behaviours was also positively associated with internalising problems (β_{ilr}=4.18, p=0.044) and total difficulties scores (β_{ilr}=7.54, p=0.031). These models further revealed that recreational screen use levels were significantly associated with psychosocial health outcomes, independent of the movement behaviour composition. Children with a high level of screen use (>2 h/day) had greater externalising problems (β=2.66, p<0.0001), total difficulties scores (β=3.68, p=0.001) and psychological distress (β=3.69, p=0.005) compared to those with a low level of screen use (≤2 h/day).

Table 7.4 presents the compositional regression models for the longitudinal association analyses. There were no significant associations between movement behaviour composition or recreational screen use levels at T1 with any of the psychosocial health outcomes at T2.

Table 7.3 Cross-sectional associations between movement behaviour composition, recreational screen use levels and psychosocial health

Psychosocial health outcomes (T1)	Movement behaviours composition (T1)										Recreational screen use levels (T1)[a]		
	Overall composition		Sleep		SED		LPA		MVPA				
	X^2	p	β_{ilr}	p	β_{ilr}	p	β_{ilr}	p	β_{ilr}	p	X^2	β	p
Internalising problems	9.70	0.021	-6.85	0.017	4.19	0.046	4.18	0.044	-1.53	0.186	2.01	0.97	0.156
Externalising problems	6.84	0.077	-6.34	0.020	2.40	0.224	3.22	0.101	0.72	0.507	17.23	2.66	<0.0001
Total difficulties	8.93	0.030	-13.31	0.006	6.48	0.064	7.54	0.031	-0.72	0.708	10.54	3.68	0.001
Prosocial behaviour	5.03	0.170	1.11	0.470	-1.38	0.226	4.61	0.249	0.89	0.161	0.42	-0.24	0.516
Psychological distress	4.24	0.237	-10.34	0.055	4.96	0.210	5.67	0.147	-0.29	0.894	7.98	3.69	0.005

Note. β_{ilr} represents isometric log-ratio (*ilr*) regression coefficient of the specific movement behaviour relative to all remaining behaviours. All models are adjusted for socio-demographic characteristics (age, sex, socio-economic status), BAZ, pubertal progression score and school clustering.

[a] Low level of recreational screen use (i.e., ≤2 h/day) as the reference category.

SED=sedentary time; LPA=light-intensity physical activity; MVPA=moderate- to vigorous-intensity physical activity.

Table 7.4 Longitudinal associations between movement behaviour composition, recreational screen use levels and psychosocial health

Psychosocial health outcomes (T2)	Movement behaviours composition (T1)										Recreational screen use levels (T1)[a]		
	Overall composition		Sleep		SED		LPA		MVPA				
	X^2	p	β_{ilr}	p	β_{ilr}	p	β_{ilr}	p	β_{ilr}	p	X^2	β	p
Internalising problems	4.75	0.191	3.52	0.228	-0.50	0.829	-1.37	0.533	-1.65	0.146	1.54	0.79	0.218
Externalising problems	2.04	0.565	3.48	0.222	-2.24	0.325	-0.08	0.969	-1.16	0.282	1.61	0.84	0.209
Total difficulties	4.49	0.213	6.78	0.129	-2.84	0.420	-1.27	0.703	-2.67	0.115	2.79	1.68	0.095
Prosocial behaviour	6.84	0.077	-0.45	0.736	-1.35	0.218	1.41	0.161	0.40	0.455	0.15	0.12	0.702
Psychological distress	4.89	0.180	5.72	0.362	1.58	0.757	-4.48	0.346	-2.82	0.256	3.13	2.54	0.077

Note. β_{ilr} represents isometric log-ratio (*ilr*) regression coefficient of the specific movement behaviour relative to all remaining behaviours. All models are adjusted for socio-demographic characteristics (T1 age, sex, socio-economic status), change in pubertal progression score, school transition experiences, T1 measures (BAZ and corresponding psychosocial health outcome) and school clustering.

[a] Low level of recreational screen use (i.e., ≤2 h/day) as the reference category.

SED=sedentary time; LPA=light-intensity physical activity; MVPA=moderate- to vigorous-intensity physical activity.

7.4 Discussion

This study investigated the cross-sectional and longitudinal associations between the 24-hour movement behaviour composition and recreational screen use with psychosocial health outcomes in children. Overall, the cross-sectional analyses revealed that the daily movement behaviour composition and recreational screen use levels were independently associated with children's psychosocial health outcomes. The movement behaviour composition was significantly associated with internalising problems and total difficulties scores. More time spent in sleep and less time spent in LPA (relative to other behaviours) were associated with less internalising problems and total difficulties scores. Conversely, higher sedentary time relative to other behaviours was associated with greater internalising problems. High levels of recreational screen use (>2 h/day) were significantly associated with greater externalising problems, total difficulties scores and psychological distress. In the longitudinal analyses, however, no significant associations were observed between the movement behaviour composition or recreational screen use levels and any of the psychosocial health outcomes.

The cross-sectional findings confirm and extend previous CoDA research (Fairclough et al. 2021; Carson et al. 2016b) by showing that the association between daily movement behaviour composition and psychosocial health outcomes is independent of children's recreational screen use levels. These findings align with the 24-hour movement guidelines (Australian Government Department of Health 2019; New Zealand Ministry of Health 2017; Tremblay et al. 2016), which recommend a daily balance of time spent in various types of movement behaviours for optimal health. Consistent with the findings of Fairclough et al. (2021), this study found that the movement behaviour composition was associated with internalising (emotional and peer/relationship problems) but not externalising problems (conduct problems and hyperactivity). However, contrary to Fairclough et al.'s study (2021), there was no association between movement behaviour composition and prosocial behaviour in the current study. This could be because a large proportion of the sample had a 'normal' prosocial behaviour profile

(i.e, 74% had prosocial scores in the 'close to average' range), which may have limited the precision and ability to detect an association between movement behaviour composition and this outcome variable (i.e., a ceiling effect) (Bang et al. 2020). Another potential explanation is that the types or contexts of activities performed (e.g., team sports or community-based activities) may also play an important role in fostering prosocial development (Eime et al. 2013; Hansen, Larson & Dworkin 2003), which could not be determined from the accelerometer-based time-use data. Nonetheless, this study did not find significant longitudinal associations between the movement behaviour composition and any of the assessed health outcomes. This may be due to the small sample size and limited changes in the cohort's psychosocial health profiles over the follow-up period. Additional research with a larger, more representative sample and longer follow-up periods is warranted to confirm this finding.

Longer duration in sleep relative to other behaviours was cross-sectionally associated with less internalising problems and total difficulties scores in the present study. This finding is consistent with existing literature that shows favourable associations between sleep duration and emotional and behavioural problems in the school-aged population (Carson et al. 2016b; Chaput et al. 2016). This is concerning given the declining sleep duration trajectories observed during childhood and adolescence (Evans-Whipp & Gasser 2019; Patte, Qian & Leatherdale 2017), with the global proportion of children meeting the current sleep duration recommendations (i.e., 9-11 h/night for ages 5-13y) ranging from 18% to 76% (based on accelerometer measures) (Roman-Viñas et al. 2016). There is also considerable evidence that meeting the sleep duration recommendations is more favourably associated with better mental health outcomes than that observed with meeting the screen time or MVPA recommendations within the 24-hour movement guidelines (Faulkner et al. 2020; Patte et al. 2020; Sampasa-Kanyinga et al. 2020). In fact, a more recent study using isotemporal substitution modelling showed that a 15-min reallocation of time from sedentary activities (screen time or homework time) or MVPA to sleep was associated with less anxiety and depressive symptoms among adolescents not meeting

the sleep duration recommendations (Gilchrist et al. 2021). This further highlights the critical role of sleep in promoting positive psychosocial development and should therefore be prioritised in future movement behaviour change interventions. Continued research is needed to explore the potential U-shaped relationship (Gilchrist et al. 2021; Chaput et al. 2016) between sleep duration and psychosocial health among children, and the possible role of reverse causation in these associations (e.g., mental health problems may precede short sleep duration) (Sampasa-Kanyinga et al. 2020; Weatherson et al. 2020).

Higher sedentary time (relative to other behaviours) was cross-sectionally associated with greater internalising problems in this study, which is consistent with the findings of Fairclough et al. (2021). Because its compositional association with internalising problems was observed to be independent of children's recreational screen use levels, this finding suggests that the negative association between sedentary behaviour and psychosocial health may not be entirely attributable to screen-based sedentary activities. This is partly supported by the findings of Suchert, Hanewinkel and Isensee (2015b), who found that higher levels of depressive symptoms were associated with both screen-based and non-screen-based sedentary time (which included time spent on passive transport, doing homework, reading and etc.) in adolescent girls, but only with non-screen-based sedentary time in boys. Another notable finding of the current study is that high levels of recreational screen use (>2 h/day) were cross-sectionally and negatively associated with externalising problems and psychological distress independent of the movement behaviour compositions. This implies that excessive screen-based sedentary activities during recreational time may be a distinct risk factor for psychosocial health (Carson et al. 2016; Hoare et al. 2016; Liu, Wu & Yao 2016). Despite the lack of observed longitudinal associations, this study do provide support for the current movement guidelines of limiting the daily amount of sedentary time, including no more than 2 h of recreational screen use (Bull et al. 2020; Australian Government Department of Health 2019; New Zealand Ministry of Health 2017; Tremblay et al. 2016) for psychosocial health benefits in the school-aged population.

More time spent in LPA relative to other behaviours was found to be associated with greater internalising problems and total difficulties scores. This finding is in line with other CoDA studies (Fairclough et al. 2021; Watson, Dumuid & Olds 2020; Carson et al. 2016b) that have also found a negative association between LPA and various health and developmental outcomes (e.g., higher adiposity and blood pressure, poorer executive function and academic achievement) among children and adolescents. This may be explained by the displacement of time spent in the remaining movement behaviours (Watson, Dumuid & Olds 2020); whereby an increase in LPA will require an equal decrease in time spent in at least one other behaviour within the 24-hour period due to the compositional nature of time-use data. This means that children who spent more time in LPA would have less time available for other movement behaviours (e.g., sleep) that may foster positive psychosocial development. In other words, the negative association of LPA with psychosocial health could be due the displacement effect rather than the time spent in LPA *per se*.

Consistent with other CoDA studies (Fairclough et al. 2021; Carson et al. 2016b), this study did not find significant association between time spent in MVPA (relative to other behaviours) and psychosocial health. The null association does not imply that MVPA *per se* is not related to psychosocial development; but rather that the amount of time spent in MVPA in association with the trade-offs in time from the other movement behaviours that the children had to make is neutral in relation to psychosocial health (Watson, Dumuid & Olds 2020). In fact, recent research that has applied compositional isotemporal substitution models demonstrates that reallocations of time between movement behaviours may have important implications for health in children and adolescents. Specifically, reallocating time from MVPA to the other behaviours (especially sedentary time) was consistently associated with greater and unfavourable predicted differences in various health outcomes (e.g., adiposity, fitness, internalising problems) than the reverse (Fairclough et al. 2021; Dumuid et al., 2018b; Fairclough et al. 2017; Carson et al. 2016b). Together, these findings emphasise the importance of considering the overall 24-hour

movement behaviour composition when examining and/or interpreting the health associations of MVPA.

This study found differential health associations for the overall movement behaviour composition (i.e., associated with internalising problems only) and recreational screen use (i.e., associated with externalising problems and psychological distress), which suggests that different types/domains of behaviours may be related to different dimensions of psychosocial health. This underscores the importance of considering the influences of both intensity- and domain-specific movement behaviours when determining the 'ideal' daily time-use composition (Dumuid et al. 2021) for optimal psychosocial health. Further research is needed to investigate the directionality and potential mechanisms underlying the compositional associations between movement behaviours and psychosocial health.

To the candidate's knowledge, this is the first compositional analysis study to investigate the independent associations of 24-hour movement behaviour composition and recreational screen use levels with children's psychosocial health outcomes in both cross-sectional and longitudinal settings. Strengths of this study included accelerometer-based measures of 24-hour movement behaviours and the use of an appropriate analytical approach to account for the compositional nature of time-use data. The statistical models were also adjusted for the important covariates (e.g., puberty) that might confound the associations of interests during this particular developmental period. A limitation of this study is the small sample size, which may limit the generalisability of the study findings. It was not possible to perform a statistical power calculation in this study due to the lack of post hoc analysis methods available for compositional linear mixed models. Next, as with all self-report measures, the self-reported data on psychosocial health and recreational screen use are subject to social desirability and recall bias. It should also be noted that the self-report measure of recreational screen use was not time-matched with the accelerometer data (i.e., not being assessed concurrently for the same time

frame); and the dichotomisation of screen use may have underestimated the extent of variation in outcomes between groups (Altman & Royston 2006). Thus, caution is warranted in interpreting these results. Because this study focused mainly on the volume and intensity of the behaviours, it remains unclear whether the observed associations with psychosocial health are moderated or mediated by the other aspects of the behaviours (e.g., types or contexts of physical activity, content of screen time). Lastly, it is important to acknowledge that the use of intensity cut-points, while validated, may have resulted in some misclassification of movement behaviours as they do not account for upper limb movements during sedentary or stationary light-intensity activities (Trost 2020; Hurter et al. 2018; van Loo et al. 2017).

7.5 Conclusion

This study found that the 24-hour movement behaviour composition and recreational screen use were independently associated with children's psychosocial health; although these associations were only evident in cross-sectional but not longitudinal analyses. Specifically, within a 24-hour context, spending more time in sleep and less time in sedentary activities and LPA while engaging in low levels of recreational screen activities may be beneficial for psychosocial health in children. These findings reinforce the importance of achieving a balance between different types of movement behaviours over a 24-hour period for optimal health benefits.

7.6 References

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Chapter 8: General discussion

The overall aim of this doctoral thesis was to explore changes in 24-hour movement behaviours and their associations with children's psychosocial health during the transition from primary to secondary school. This thesis set out to i) examine changes in 24-hour movement behaviour time-use composition using accelerometry (Chapter 5) and time-use diary methods (Chapter 6); and ii) investigate the cross-sectional and longitudinal associations between time spent in 24-hour movement behaviours and psychosocial health outcomes during the school transition period (Chapters 6 and 7). This concluding chapter summarises the main findings of the thesis and discusses them considering other academic evidence. Additionally, this chapter discusses the implications of the research findings and the overall strengths and limitations of the thesis. Finally, this chapter provides recommendations for future research and the overall conclusions of the thesis.

8.1 Overview of findings

The systematic review presented in Chapter 3 showed that there was a lack of research exploring concurrent changes in physical activity, sedentary behaviour and sleep over a 24-hour period across the primary to secondary school transition, all of which are the co-dependent parts of the 24-hour movement behaviour composition. To address this knowledge gap, two studies were conducted to examine the changes in 24-hour movement behaviour composition across the school transition period using different measurement methods, and to identify the potential moderators of the change in movement behaviour composition (Chapters 5 and 6).

Chapter 5 explored changes in the 24-hour movement behaviour composition using wrist-worn accelerometry data collected from a sample of children enrolled in the final year of primary school (Year 6; aged 10-12y) at baseline and in the first year of secondary school (Year-7; aged 11-13y) at follow-up (n=83). This study showed that the overall movement behaviour

composition changed unfavourably following the transition to secondary school, with increased time spent sedentary and decreased time in sleep, light-intensity physical activity (LPA) and moderate- to vigorous-intensity physical activity (MVPA). In relation to the day-type difference in behavioural changes, the weekday's composition demonstrated similar patterns but larger magnitudes of changes than the weekend's composition. The observed increase in sedentary time may be attributed in part to a concurrent increase in recreational screen use and out-of-school educational activities. These behavioural changes were also reflected in a decrease in the proportion of children who met the Australian 24-Hour Movement Guidelines, with the largest decline observed in the sleep duration guidelines. Lastly, the change in overall movement behaviour composition was not moderated by children's socio-demographic (sex, socio-economic status) or health characteristics (body weight status and pubertal development).

Chapter 6 examined changes in time spent in eight domains of 24-hour movement behaviours (Self-care/Domestic, Physical Activity, Social, Education, Recreational Screen Use, Quiet Time, Sleep and Passive Transport) using time-use diary data collected from a population-based sample of children aged 10-11y at baseline and 12-13y at follow-up (n=909). The analytical sample comprised a larger proportion of children who completed their time-use diaries on a school day (67.4%) than on a non-school day (32.6%) at both time points. This study found a more drastic change in movement behaviour composition among the school day sample compared to the non-school day sample. Regardless of the day type, children reported spending significantly more time in social activities and less time in sleep following their transition to secondary school. Additionally, the change in the overall movement behaviour composition was not moderated by the change in the school environment. This study also investigated the association between the change in movement behaviour composition and the change in psychosocial health during the school transition period. Only one of the four psychosocial health outcomes examined (i.e., prosocial behaviour) was related to the change in overall movement behaviour composition in boys and none were identified in girls. Among boys,

increased time spent in social activities and recreational screen use (relative to other activity domains) were associated with decreased prosocial behaviour. However, the effect sizes were small and may not be clinically relevant.

Finally, Chapter 7 investigated the cross-sectional and longitudinal associations between 24-hour movement behaviours, recreational screen use and psychosocial health outcomes. This study found that the overall movement behaviour composition and recreational screen use were cross-sectionally and independently associated with psychosocial problems. Specifically, more time spent in sleep and less time spent in LPA (relative to other behaviours) were associated with lower levels of internalising problems and total psychosocial difficulties. Conversely, higher sedentary time relative to other behaviours was associated with greater internalising problems. Furthermore, high levels of recreational screen use (>2 h/day) were consistently associated with greater externalising problems, total psychosocial difficulties and psychological distress. However, no longitudinal associations were found between the movement behaviour composition or recreational screen use and any of the psychosocial health outcomes.

8.2 Discussion of findings

This thesis demonstrated that the transition from primary to secondary school was accompanied by an unfavourable change in children's 24-hour movement behaviour composition. As highlighted in Chapter 5, the change in overall movement behaviour composition was driven by concurrent changes in all three movement behaviour components, with an increase in sedentary time being offset by decreases in both sleep and physical activity time-use components based on 24-hour accelerometry measures. This study confirms and extends previous findings from individual movement behaviour research (Chong et al. 2020; Pearson et al. 2017) with further evidence supporting the use of an integrated approach to better understand children's 24-hour movement behaviour patterns during this school transition period.

Considering the co-dependent nature of movement behaviour data (Chastin et al. 2015), it is important that the changes in individual movement behaviours be interpreted in relation to each other. As discussed in Chapter 5, the increase in total sedentary time may be partly attributed to the concurrent increase in sedentary recreational screen use and out-of-school educational activities, which are also likely to have an impact on children's sleep and physical activity behaviours. It has been suggested that increased time spent in these activities could have a negative impact on children's sleep patterns (e.g., delay in sleep onset timing) (Hale & Guan 2015; Evans-Whipp & Gasser 2019), resulting in a decrease in sleep duration. Further, an increase in recreational screen use may displace time spent in more active pursuits during the after-school period (e.g., participation in sports) (Yu & Baxter 2016), a period that that has been identified as an important contributor to the overall decline in physical activity during this transition period (Chong et al. 2020). There is also evidence suggesting that shorter sleep duration the preceding night may lead to higher sedentary time and lower physical activity the following day in children, and vice versa (Lin et al. 2018). This indicates that a full-composition intervention approach may be the most effective strategy to assist children in improving their movement behaviour profiles during the transition to secondary school.

An important finding of this thesis was the day-type differences in behavioural change observed during the school transition period. It was consistently observed in Chapters 5 and 6 that the change in 24-hour movement behaviour composition appeared to be greater on weekdays than on weekends, despite methodological differences between the two studies (accelerometry vs. time-use diary). This highlights that weekdays may be a focus for movement behaviour interventions targeting the primary to secondary school transition period. Greater changes in weekday behaviours may be partly explained by an increased academic workload and responsibilities (e.g., more homework and self-directed learning, exposure to a range of new subjects) associated with the transition to secondary school (McGaughey et al. 2020; Maguire & Yu 2015), which are likely to have a significant impact on children's weekdays' time-use

patterns and, consequently, movement behaviour profiles (e.g., more time spent on doing homework while sitting, less time available for physical activity). Other school-level factors, such as the length of break and provision of extracurricular physical activity, may also contribute to behavioural change on a typical weekday during this transition period (McGaughey et al. 2020; Morton et al. 2016a).

Chapter 5 also found that the change in the 24-hour intensity-specific movement behaviour composition was not moderated by children's socio-demographic (sex, socio-economic status) and health characteristics (body weight status and pubertal development). It was not possible to compare this finding with the literature due to a lack of integrated movement behaviour research in this topic area (Chong et al. 2020). However, as noted in Chapter 2, the influence of socio-demographic (e.g., sex, parental education) and health factors (e.g., body weight status) on behavioural changes during the school transition period appears to vary by the dimensions of behaviours, with significant effects observed mostly for the specific domain or type of activity (e.g., education-related sedentary time) (Rutten et al. 2014) but not for intensity-based measures (e.g., MVPA) (Barr-Anderson et al. 2017; De Meester et al. 2014; Corder et al. 2015). This was also observed in Chapter 6 where a more pronounced change in the domain-specific movement behaviour composition was identified in boys on a non-school day (e.g., increased recreational screen use, decreased education-related activities) compared to girls. Taken together, these findings suggest that socio-demographic and health factors may have an impact on how children reallocate their time between different domains or types of activities during this transition period, which may not be reflected in changes in intensity-based measures (e.g., boys and girls may accumulate a similar amount of sedentary time through engagement in different types of sedentary activities). It is important to note, however, that the moderator analysis was performed on a relatively small sample (n=83), which might not be adequately powered to detect statistically significant differences between subgroups.

Despite accumulating evidence suggesting the role of the school environment plays in preventing or attenuating negative changes in movement behaviours during the school transition period (Morton et al. 2016a; De Meester et al. 2014), the extent to which these changes are attributed to the change in school environment *per se* remains largely unknown (Pearson et al. 2017). Previous Australian research (n=243) sought to address this knowledge gap by comparing changes in physical activity and sedentary behaviour between two groups of children who experienced different types of transition, i.e. transitioning to a new school or remaining in the same school environment for secondary education (Marks et al. 2015). The authors found that children who moved to a new secondary school reported experiencing greater changes in specific types of behaviours (e.g., reduced frequency in cycling to/from school, greater increases in recreational screen time on both weekdays and weekends) compared to those who remained at the same school (Marks et al. 2015). However, the present thesis showed that the change in school environment had no significant moderating effect on the change in 24-hour movement behaviour composition among a large national sample of children (Chapter 6). The discrepancy in results might be explained by methodological differences between the two studies, with the current study focusing on changes in the full 24-hour movement behaviour composition rather than on specific activity types. It is also important to note that both studies did not account for the influence of school environmental characteristics (Morton et al. 2016b), which may have moderated or mediated this analysis. Nonetheless, this thesis provides initial evidence suggesting the change in school environment may not be the sole factor contributing to the change in children's movement behaviour composition during this transition period.

Another noteworthy finding was that adherence to the new 24-hour integrated movement guidelines declined substantially over the school transition period (Chapter 5). More than half the sample transitioned from meeting to not meeting the individual guidelines or remained non-adherent at both time points, with the largest decrease observed in adherence to the sleep guidelines. This is concerning as recent research has shown a prospective association between

changes in adherence to movement guidelines and adolescent's mental health outcomes, with those who consistently adhere to the guidelines (particularly sleep guidelines) reporting fewer depressive symptoms (Patte et al. 2020) and greater flourishing (Faulkner et al. 2020) compared to those who transitioned from meeting to not meeting or remained non-adherent. These findings emphasise the importance of educating and supporting children in continuing to meet the movement behaviour guidelines throughout the school transition period.

It is critical to note, however, that there is still uncertainty about whether the observed behavioural changes are attributable to the school transition *per se* or are confounded by other age-related developmental changes (e.g., transition from childhood to adolescence) (Kontostoli et al. 2021; Kemp et al. 2020; Chaput, Dutil & Sampasa-Kanyinga 2018). As discussed in Chapter 3, there is some evidence that the changes in movement behaviours are not linear across the school transition period (Lau et al. 2017) and appear to be related to differences in primary and secondary school environmental characteristics (e.g., policies, programmes and facilities for physical activity) (Morton et al. 2016; Marks et al. 2015; De Meester et al. 2014). Further, the study reported in Chapter 5 also ruled out the possibility of children's pubertal status as a potential moderator of the change in movement behaviour composition. Although limited, these findings seem to suggest that the effect of the school transition on children's movement behaviours is distinct from those of the broader, age-related developmental influences.

Despite considerable changes in children's 24-hour movement behaviour composition, there was little association between these changes and concurrent changes in their psychosocial health during the school transition period. As shown in Chapter 6, only one of the four SDQ psychosocial outcomes examined (i.e., prosocial behaviour) was related to the change in domain-specific movement behaviour composition in boys and none were identified in girls. While the inconsistency in the associations observed may be explained by methodological limitations (e.g., the use of single-day time-use diary data) and/or little change in psychosocial

outcomes (especially among girls), it is possible that sex- and outcome-specific associations exist between movement behaviour composition and psychosocial health in children. This was suggested in the findings of a recent cross-sectional study conducted in the United Kingdom (Fairclough et al. 2021), in which sex was identified as a significant predictor in compositional models of intensity-specific movement behaviours and prosocial behaviour for both primary (n=210) and secondary school (n=149) samples; though further sex-stratified analyses revealed non-significant associations in either subgroup. Additionally, this cross-sectional study found that the overall movement behaviour composition was associated with prosocial behaviour but not with other SDQ outcomes in primary school children (Fairclough et al. 2021), which was consistent with the results of the longitudinal analysis of association between the change in movement behaviour composition and the change in psychosocial health reported in Chapter 6. Further research with multiple days of valid behavioural measures and a longer follow-up period is warranted to test this hypothesis on a range of psychosocial health measures.

Chapter 6 also highlighted the possibility of a domain-specific association between movement behaviours and children's psychosocial health. Specifically, increased time spent in social activities and recreational screen use at the expense of other activity domains during a 24-hour period was associated with lower levels of prosocial behaviour in boys following their transition to secondary school. However, the magnitude of these associations were small (effect sizes <0.10 based on 30-minute 'one-for-remaining' longitudinal reallocation analysis) and unlikely to be clinically meaningful. This finding is consistent with previous longitudinal research demonstrating that increased recreational screen time may have a minimal effect on psychosocial health outcomes in children and adolescents (Sanders et al. 2019; Babic et al. 2017). This may be partially related to the use of a subjective, self-report measurement tool that does not capture the 'quality' aspects of the behaviours (e.g., the content and context of screen use), which could have a buffering effect on their associations with psychosocial health (Stiglic & Viner 2019). It is also possible that the adverse effects of screen use may accumulate over

time and that stronger associations may be detected with a longer follow-up period (Babic et al. 2017).

The health effects of recreational screen use were further explored in Chapter 7 by examining its independent association with psychosocial health outcomes adjusted for the 24-hour intensity-specific movement behaviour composition. It was identified that spending more than 2 h/day in sedentary recreational screen use was related to greater externalising problems and psychological distress independent of the movement behaviour composition; although the associations were only evident in the cross-sectional but not longitudinal analyses. This finding adds to a growing body of evidence suggesting that excessive screen use for recreational purposes may be a distinct risk factor for children's psychosocial health and should be treated separately from other forms of screen use or non-screen-based sedentary behaviours (Sanders et al. 2019; LeBlanc et al. 2017; Hoare et al. 2016). This is also consistent with the 24-hour movement guidelines (Australian Government Department of Health 2019; New Zealand Ministry of Health 2017; Tremblay et al. 2016), which specifically recommend that school-aged children and adolescents spend no more than 2 h/day on sedentary recreational screen time for optimal health, in addition to limiting prolonged periods of sitting, engaging in high levels of physical activity and getting adequate sleep.

As demonstrated in Chapter 7, the 24-hour intensity-specific movement behaviour composition was cross-sectionally but not longitudinally associated with children's psychosocial health, after adjusting for their recreational screen use levels. In contrast to the associations observed with recreational screen use, the overall movement behaviour composition was only associated with internalising problems. This suggests the possibility that different dimensions of movement behaviours (domain vs. intensity) may contribute differently to psychosocial health in children. In relation to the relative associations of individual movement behaviours, spending more of the 24-hour period in sleep and less in sedentary activities and LPA were associated with fewer

internalising problems. This finding is generally consistent with two other CoDA-based cross-sectional studies that also highlighted the beneficial associations of sleep (Carson et al. 2016) or adverse associations of sedentary time (Fairclough et al. 2021) with psychosocial health outcomes. These associations, however, should be interpreted through a compositional lens. For example, the negative association of sedentary time could be explained by the displacement of time spent in other behaviours within the 24-hour composition (i.e., sleep and/or physical activity) that may foster positive psychosocial development, rather than the time spent in sedentary activities *per se*. In other words, the negative effects of sedentary time could potentially be negated by reallocating part of it to sleep or physical activity, as suggested by Fairclough et al.'s study (2021) using compositional isotemporal substitution models. This aligns with the concept of the new 24-hour movement paradigm (Rosenberger et al. 2019; Pedišić, Dumuid & Olds 2017; Tremblay et al. 2016), which emphasises the importance of considering the integrated relationships among movement behaviours across a 24-hour day. Nevertheless, additional longitudinal research with a larger sample and longer follow-up period is needed to confirm the directionality/temporal sequence of these associations.

Lastly, it is important to acknowledge that the data analysed in this thesis were gathered prior to the outbreak of the COVID-19 pandemic, which has introduced significant disruptions to many aspects of a child's life. Compared to the pre-pandemic period, studies consistently reported a decrease in physical activity and an increase in screen time and sleep duration among school-aged populations during the pandemic (Paterson et al. 2021). There also appears to be negative impact on children's psychosocial health; in particular, children with existing mental health conditions were reportedly experiencing an exacerbation of symptoms during the pandemic (Goldfeld et al. 2022). As a result, it is speculated that the observed behavioural changes during the school transition period will be exacerbated even further during/after the pandemic, which are likely to have some impacts (direct or indirect) on children's psychosocial development.

8.3 Implications of findings

The findings of this thesis have several important implications for future research and practice. First, this thesis identified the need for an integrated time-use intervention approach that simultaneously addresses sleep, sedentary behaviour and physical activity to tackle the behavioural changes associated with the transition from primary to secondary school. This implies that future interventions should focus on developing initiatives that benefit all three movement behaviours (i.e., reducing sedentary time while promoting sufficient sleep and physical activity), which is also consistent with the integrated part of the Australian 24-Hour Movement Guidelines for Children and Young People (Australian Government Department of Health 2019).

Second, this thesis established that weekdays may be the optimal time segment for movement behaviour interventions due to greater behavioural changes observed during this school transition period. Considering the influence of the school environment on children's behaviours (Morton et al. 2016b), and that children spend a large proportion of their time during a typical weekday at school, school appears to be an ideal setting for the delivery of interventions. Currently, different school-level intervention strategies have been proposed to be effective for improving individual movement behaviours (e.g., delaying school start time for improving sleep outcomes on school nights (Minges & Redeker 2016); adopting flexible learning spaces in schools for reducing sedentary time (Kariippanon et al. 2019); implementing classroom physical activity breaks and physically active learning approaches for increasing physical activity (Jones et al. 2020)). Increased efforts, however, are needed to evaluate their efficacy and effectiveness in changing the overall movement behaviour composition beneficially, as a strategy may improve one behaviour while concurrently having a negative impact on another. Additionally, given the evidence of specific changes in physical activity and sedentary behaviour during the outside-of-school period (Chong et al. 2021; Chong et al. 2020; Remmers et al. 2020; Marks et al. 2015), it is important that other settings (e.g., outside-school hours childcare centres (Virgara

et al. 2021), family (Huang et al. 2021) and neighbourhood environments (D'Haese et al. 2015)) be considered in order to promote a healthy balance of time between behaviours across the whole 24-hour day.

This thesis demonstrated the collective and relative impact of 24-hour movement behaviours on children's psychosocial health, though further longitudinal research is warranted to confirm the findings. This reinforces the importance of adopting an integrated approach to consider the overall time-use composition of movement behaviours when examining and interpreting their associations with health (Rollo, Antsygina and Tremblay 2020).

Lastly, this thesis found that the intensity and domain of movement behaviours may have differential impacts on children's psychosocial health outcomes. This underscores the importance of measuring and analysing both intensity- and domain-specific movement behaviour compositions in future studies to further our understanding of the associations between 24-hour movement behaviours and psychosocial health in children. This may have important implications for how the 'optimal' 24-hour movement behaviour composition (i.e., the "Goldilocks Day") can be conceptualised for the population (Dumuid et al. 2021a), as their effects on health outcomes, at least in the psychosocial health domain, may vary depending on the classification system used (e.g., intensity-based vs. domain-based). To continue progressing this research area, there is a need for developing a low-burden, high-fidelity 24-hour surveillance instrument that can simultaneously capture different dimensions (including the type and context) of movement behaviours (Dumuid, Olds & Sawyer 2021b).

8.4 Strengths and limitations

This section discusses the strengths and limitations of this thesis. Other information specific to the individual studies has been detailed in the corresponding study chapter (see Chapters 5 to 7).

8.4.1 Strengths

The overall strengths of this thesis are noted below:

i. In line with the new integrated 24-hour movement behaviour paradigm (Rosenberger et al. 2019; Pedišić, Dumuid & Olds 2017), this thesis adopted an integrated approach where all movement behaviours (sleep, sedentary behaviour and physical activity) were examined as the co-dependent parts of a 24-hour composition.

ii. A CoDA approach was adopted for the analysis of movement behaviour data, accounting for the compositional properties and co-dependent nature of time-use variables (Chastin et al. 2015). In particular, this thesis applied CoDA to the analysis of longitudinal data, which is currently lacking in this research area.

iii. The use of both device-based (Chapter 5: accelerometer) and subjective measures of movement behaviours (Chapter 6: time-use diary) enabled a more nuanced understanding of the change in children's 24-hour movement behaviour composition as they transition from primary to secondary school.

iv. The thesis further advanced the understanding of the associations between 24-hour movement behaviours and psychosocial health in children by exploring the longitudinal nature of the associations using 'change-change' (Chapter 6) and prospective analyses (Chapter 7).

8.4.2 Limitations

This thesis had several limitations:

i. This thesis analysed data from two surveys that were conducted at different time periods (Chapters 5 and 7: 2018-2020 vs. Chapter 6: 2010-2012) with different lengths of follow-

up (11-12 months vs. 2 years). As such, the findings on children's movement behaviours and psychosocial health profiles may not be directly comparable across the three studies included in this thesis.

ii. Because the examination of changes in movement behaviours was limited to two data points, it was not possible to determine the trends in movement behaviours over the school transition period.

iii. Data on 24-hour movement behaviours were collected over a relatively short period of time (i.e., 3-6 valid days for accelerometer measures and 1 day for time-use diary), which may not accurately reflect the habitual movement behaviour patterns of the participants. However, it has been demonstrated that having at least 3 to 5 days of wrist-worn GENEActiv accelerometer data would be sufficient to provide reliable estimates of sleep, sedentary time and physical activity among children aged 7-12y (Antczak et al. 2021).

iv. This thesis focused primarily on examining the associations between movement behaviours and psychosocial difficulties (e.g., internalising and externalising problems), which may not be generalisable to other dimensions of psychosocial health (e.g., flourishing) (Gilchrist et al. 2021).

v. The small sample sizes and the use of a convenience sampling approach may have limited the interpretability and generalisability of the results reported in Chapters 5 and 7.

vi. There was an inconsistency between Chapters 6 and 7 in the analysis of the association between recreational screen time and psychosocial health (i.e., screen time was included as part of the movement behaviour composition vs. screen time was analysed separately from the movement behaviour composition) due to the current methodological or

measurement challenges in the field. It is acknowledged that screen time can be conceptualised as a type of sedentary behaviour and therefore can be considered as part of the 24-hour movement behaviour composition. However, particularly in the case of psychosocial health outcomes, the mechanisms through which recreational screen use influences health outcomes might be due to factors other than sitting/being sedentary (Stiglic & Viner 2019), and therefore recreational screen use can also be conceptualised as a health behaviour separate to the common types of movement behaviours (i.e., sleep, sedentary behaviour and physical activity). The cross-sectional findings that recreational screen use was associated with mental health outcomes independent of the movement behaviour composition supports this (Chapter 7). The field may require further conceptualisation of screen time and sedentary behaviours to most appropriately represent time spent in these behaviours within the overall movement behaviour composition.

8.5 Recommendations for future research

This thesis has contributed new evidence to time-use epidemiology by demonstrating the change in 24-hour movement behaviour composition and their collective associations with children's psychosocial health during the transition from primary to secondary school. This section provides several recommendations for future research that may strengthen and advance the evidence base in these areas of research.

8.5.1 Recommendations for future research examining changes in 24-hour movement behaviours across the school transition

As noted in Section 8.4.2, the examination of behavioural changes in this thesis (Chapters 5 and 6) was limited by the use of only two data points, precluding the ability to determine the trends in movement behaviours over time. This could be addressed by a future longitudinal study that includes multiple data points spanning the pre-, during, and post-school transition phases. For example, a 3-year study with annual follow-ups from the final year of primary school through

the second year of secondary school would provide an opportunity to examine if the change in overall movement behaviour composition was more pronounced during the transition phase relative to the post-transition phase. This may also enable investigation of whether the school transition had an acute or long-term effect on children's movement behaviour composition, which was not possible in the present thesis.

In this thesis, the change in movement behaviour composition was explored by calculating the log-ratio difference between the population's mean composition at primary and secondary school time points (Chapters 5 and 6). Future research may use other statistical methods to provide a more in-depth understanding of the patterns of behavioural change that occur during this transition period. For example, a time flow analysis may be performed to visualise the time flow patterns among movement behaviour components, which may assist in identifying the primary behaviour(s) responsible for the increase/decrease in time allocated to specific behaviours (e.g., whether the increase in screen time was due only to decreases in time spent being physically active or from other activity domains) (Olds et al. 2018). Alternatively, analytical approaches such as cluster analysis (Everitt et al. 2011) and latent class/profile analysis (Samuelsen & Raczynski 2013) may be applied to identify subgroups of individuals who share similar behavioural profiles over time. Such information may help identify the most prevalent patterns of behavioural change in the population and the subgroups most at risk of developing unhealthy movement behaviour profiles during this key life transition.

While this thesis attempted to explore the moderating effects of socio-demographic and health characteristics on changes in children's movement behaviour composition (Chapter 5), the analysis was constrained by a small sample size. It is recommended that future research replicate this analysis using a larger sample size to confirm this thesis's findings. Additionally, given the current evidence regarding the influences of environmental factors (e.g., access to physical activity equipment at home (Barr-Anderson et al. 2017), availability of walking and

cycling infrastructure in neighbourhoods (D'Haese et al. 2015), active schoolyards and playgrounds (De Meester et al. 2014)) on specific movement behaviour (i.e., physical activity), future research should seek to examine these factors as potential moderators of the change in overall movement behaviour composition using the CoDA approach. This information may be used to guide the development of future school transition-related strategies to promote healthy levels of movement behaviours.

8.5.2 Recommendations for future research examining associations between 24-hour movement behaviours and psychosocial health

The studies described in Chapters 6 and 7 were the first known investigations exploring the longitudinal associations between 24-hour movement behaviours and children's psychosocial health using the CoDA approach. Chapter 6 revealed inconsistent associations between the change in domain-specific movement behaviour composition and the change in psychosocial health across sex subgroups and outcome measures during the school transition. One limitation of this study was that the movement behaviour data were derived from a single-day time-use diary completed on a random day of the week at each time point, which may not reflect the population's habitual behaviours. Additionally, because the data used in this study were collected over a decade ago, the findings may not be generalisable to contemporary children of the target ages. It is recommended that future research replicate this study by employing multiple days of time-use diary and/or accelerometry measures (e.g., a 7-day protocol) and a diverse set of psychosocial health outcomes. This may provide more definitive evidence on the role of 24-hour movement behaviours in fostering children's psychosocial health development during this transition period. It may also provide further evidence to justify whether the association between 24-hour movement behaviour composition and psychosocial health differs by sex and dimensions of psychosocial health.

Chapter 7 showed that the intensity-specific movement behaviour composition and recreational screen use levels were both cross-sectionally but not longitudinally associated with psychosocial health. This study, however, was limited by a small sample size and a relatively short follow-up period (~1 year), as well as by the use of self-report measure of recreational screen use that was not time matched with the accelerometer measures of movement behaviours. To address these issues, future research should employ a more rigorous methodology by including i) larger and more representative samples; ii) longer follow-up periods; and iii) more advanced methodologies (e.g., ecological momentary assessment, device-based pattern recognition approach (Fairclough et al. 2021)) for classifying 24-hour time-use data into different types/contexts and intensities of behaviours. This may allow for a more accurate examination of the potential impact of screen time relative to other behaviours (and vice versa) on children's psychosocial health.

Lastly, future longitudinal research may explore a different facet of this area by investigating associations between adherence to the 24-hour movement guidelines and psychosocial health outcomes. This may involve examining the differences (or changes) in outcome measures by the patterns of change in adherence to the individual and integrated movement guidelines (as identified in Chapter 5); or the prospective associations between adherence to the movement guidelines during primary school and outcomes during secondary school. Such studies may contribute to establishing evidence of the health benefits of adherence to the 24-hour movement guidelines, as well as inform decision makers as to whether specific guidelines or recommendations are needed for the promotion of psychosocial development in children and adolescents.

8.6 Conclusion

This thesis has provided new evidence to advance the understanding of children's 24-hour movement behaviours and their associations with psychosocial health during the transition from

primary to secondary school. Using a compositional analytical approach, this thesis revealed an unfavourable change in children's 24-hour movement behaviour composition across the school transition period, particularly on weekdays. An integrated intervention approach addressing all three movement behaviour components (sleep, sedentary behaviour and physical activity) may be the most effective strategy for improving children's movement behaviour profiles during this transition period. Further, there was suggestive evidence that the 24-hour composition of movement behaviours may have important implications for children's psychosocial development, although further longitudinal research is necessary to clarify the direction of causality of these associations. This thesis also demonstrated that the intensity and domain of movement behaviours may have differential impacts on children's psychosocial health outcomes and should be considered within future studies in this topic area. To conclude, the findings of this thesis collectively lend support to the adoption of the new integrated 24-hour movement behaviour paradigm (Rosenberger et al. 2019; Pedišić, Dumuid & Olds 2017; Tremblay et al. 2016), which acknowledges the importance of considering all movement behaviours over a 24-hour period as a collective component for promoting and maintaining holistic health and wellbeing in children.

8.7 References

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Appendices

Appendix 3.1 Search strategy for the systematic review

#	Search terms	Date Limit
1	child* OR adolescen* OR youth	1990 – May 2019
2	"primary school" OR "elementary school" OR "secondary school" OR "middle school" OR "high school"	1990 – May 2019
3	longitudinal OR follow-up OR cohort OR tracking OR transition	1990 – May 2019
4	"physical activit*" OR sport OR exercise OR sedentar* OR "sedentary behavio*" OR computer* OR "TV viewing" OR "video gam*" OR "electronic gam*" OR internet OR tablet OR smartphone OR "social media" OR television OR screen-time OR screen-based OR "screen based" OR "non-screen-based" OR sitting OR sleep*	1990 – May 2019
5	1 AND 2 AND 3 AND 4	

Appendix 3.2 Risk of bias assessment of the included articles

Authors & Year	Selection bias[a]	Attrition bias[b]	Detection bias[c]	Overall assessment[e]
Cooper et al. (2012)	HIGH risk of bias	HIGH risk of bias	LOW risk of bias[d]	HIGH risk of bias
Jago, Page & Cooper (2012)	HIGH risk of bias	HIGH risk of bias	LOW risk of bias[d]	HIGH risk of bias
De Meester et al. (2014)	LOW risk of bias	Accelerometer measure HIGH risk of bias Self-report measure HIGH risk of bias	Accelerometer measure LOW risk of bias[d] Self-report measure LOW risk of bias	LOW risk of bias
D'Haese et al. (2015)	LOW risk of bias	HIGH risk of bias	LOW risk of bias	LOW risk of bias
Marks et al. (2015)	HIGH risk of bias	Accelerometer measure HIGH risk of bias Self-report measure LOW risk of bias	Accelerometer measure LOW risk of bias[d] Self-report measure HIGH risk of bias	HIGH risk of bias
Barr-Anderson et al. (2017)	HIGH risk of bias	HIGH risk of bias	LOW risk of bias[d]	HIGH risk of bias

[a] Were the participants likely to be representative of the target population?

[b] Did an adequate percentage of participants (≥70%) have complete data?

[c] Did the measure of behaviour demonstrate adequate reliability and/or validity in children or adolescents? - ICC≥0.4 (Cicchetti & Sparrow 1981), Kappa≥0.4 (Cicchetti & Sparrow 1981), r≥0.5 (Hinkle, Wiersma & Jurs 2003) or ROC-AUC≥0.7 (Zweig & Campbell 1993).

[d] The validity of cut-point definition was determined based on the results of a comparative validity study (Trost et al. 2011).

[e] An overall rating of 'LOW' ROB was applied for studies with at least two out of three items coded as 'LOW' ROB.

Appendix 3.3 Summary of articles in systematic review that measured changes in physical activity across the transition from primary to secondary school

Authors & Year	Outcome assessed (minutes/day, unless otherwise stated)	Primary school[a]	Secondary school[a]		Mean change (secondary minus primary)[a]	Direction of change	Analysis of change
		Final year	First year	Second year			
Cooper et al. 2012	Weekday MVPA (Accel)	60.6 (21.6)	63.1 (23.6)	-	2.6 (95%CI: 0.5-4.7)*	Increase	Paired sample t-test
Jago, Page & Cooper 2012	After-school MVPA (Accel)	n/a	n/a	-	B: -4.60 (17.21)*** G: -2.63 (13.08)***	Decrease Decrease	Paired sample t-test[b]
	Weekend MVPA (Accel)	n/a	n/a	-	B: 4.68 (49.00)*** G: 1.98 (29.56)***	Increase Increase	
De Meester et al. 2014	Weekday MVPA (Accel)	27.69 (19.15)	-	31.74 (23.97)	n/a*	Increase	Cross-classified multilevel regression models
	Active transport to and from school (SR)	11.35 (13.35)	-	17.23 (17.83)	n/a***	Increase	
	Extracurricular PA at school (SR)[c]	23.12 (18.67)	-	10.72 (15.09)	n/a***	Decrease	
	Total PA (SR)[d]	80.62 (41.62)	-	69.49 (40.42)	n/a**	Decrease	
D'Haese et al. 2015	Walking for transport during leisure time (SR)	B: 9.11 (12.58) G: 6.85 (10.24)	-	B: 5.93 (10.21) G: 6.68 (10.27)	B: -3.18 (16.20)* G: -0.17 (14.50)	Decrease No change	Cross-classified multilevel regression models (adjusted for
	Cycling for transport during leisure time (SR)	B: 12.79 (14.12)	-	B: 11.06 (14.22)	B: -1.73 (20.04)	No change	

	Sports during leisure time (SR)	G: 7.60 (10.09) B: 33.43 (25.15) G: 25.23 (23.43)	- -	G: 6.92 (9.34) B: 29.85 (27.14) G: 18.46 (21.00)	G: -0.68 (13.75) B: -3.58 (37.00)** G: -6.77 (31.46)***	No change Decrease Decrease	educational level of mother and father)
Barr-Anderson et al. 2017	Total PA[e] (minutes/hour) (Accel)	<u>Overall</u> 23.3 (SE 0.18) <u>Race/Ethnicity</u> Black: 29.1 (SE 0.27) Hispanic: 27.9 (SE 0.54) White: 27.8 (SE 0.26) <u>Parent education</u> <=High school:28.7 (SE 0.27) >High school: 28.1 (SE 0.24)	<u>Overall</u> 24.3 (0.19) <u>Race/Ethnicity</u> Black: 24.7 (SE 0.28) Hispanic: 24.2 (SE 0.55) White: 24.0 (SE 0.27) <u>Parent education</u> <=High school:24.7 (SE 0.28) >High school: 24.0 (SE 0.24)	<u>Overall</u> 22.7 (0.19) <u>Race/Ethnicity</u> Black: 22.7 (SE 0.29) Hispanic: 23.0 (SE 0.57) White: 22.4 (SE 0.28) <u>Parent education</u> <=High school:22.9 (SE 0.29) > High school: 22.4 (SE 0.25)	n/a n/a n/a n/a n/a	"Minutes/hour of total PA declined from fifth to sixth grade and remained stable from sixth to seventh grade among all racial/ethnic and SES groups." *(see Results, paragraph 1, pp. 565)*	NS

[a] Data presented in mean (standard deviation), unless otherwise stated.
[b] Manual calculation based on the reported mean changes.
[c] Defined as the sum of participation in PA during playtime, lunch break, after-school hours or at class or school tournaments.
[d] Defined as the sum of participation in active transport, physical education, extracurricular PA at school and sports during leisure time.
[e] Defined as the sum of time spent in light PA and MVPA.
Statistical significance levels: * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.
PA=physical activity; MVPA=moderate- to vigorous-intensity PA; LPA=light-intensity PA; Accel=accelerometer; SR=Self-report questionnaire; B=boys; G=girls; n/a=data not given/stated; SE=standard error; CI=confidence interval.

Appendix 3.4 Summary of articles in systematic review that measured changes in combined movement behaviours across the transition from primary to secondary school

Authors & Year	Movement behaviours	Outcome assessed (minutes/day, unless otherwise stated)	Primary school[a]	Secondary school[a]	Mean change (secondary minus primary)[a]	Direction of change	Analysis of change
			Final year	First year			
Marks et al. 2015	PA	Daily MVPA (Accel)	51 (18)	48 (17)	-4 (13)*	Decrease	Paired sample t-test
		Daily LPA (Accel)	219 (39)	196 (40)	-23 (33)*	Decrease	
		Being 'very active' after school (SR)[b]	64 (56)	75 (67)	10 (66)*	Increase	
		Being 'very active' during weekend (SR)[b]	84 (82)	83 (85)	-1 (106)	No change	
	SB	Daily SED (Accel)	476 (69)	492 (86)	16 (76)*	Increase	
		Weekday leisure ST (SR)	135 (111)	152 (114)	17 (126)*	Increase	
		Weekend leisure ST (SR)	143 (121)	158 (160)	16 (164)	No change	
		Weekday homework ST (SR)	36 (49)	61 (64)	25 (67)*	Increase	
		Weekend homework ST (SR)	19 (32)	31 (45)	12 (48)*	Increase	

[a] Data presented in mean (standard deviation), unless otherwise stated.
[b] Defined as participation in sports, dance or play games in which children were very active.
Statistical significance levels: * $p < 0.05$.
PA=physical activity; MVPA=moderate- to vigorous-intensity PA; LPA=light-intensity PA; SB=sedentary behaviour; SED=sedentary time; ST=screen time; Accel=accelerometer; SR=Self-report questionnaire.

Appendix 4.1 Ethical approval for Survey 1 (HREC 2017/255)

UNIVERSITY
OF WOLLONGONG
AUSTRALIA

APPROVAL LETTER
In reply please quote: HE17/255
Further Information Phone: 4221 3386

19 July 2017

Dear Professor Okely,

I am pleased to advise that the application detailed below has been ***approved***.

Ethics Number:	2017/255
Approval Date:	18/07/2017
Expiry Date:	17/07/2018
Project Title:	Understanding 24-hour movement behaviours and their associations with children's psychosocial health across the primary-secondary school transition
Researchers:	Okely Tony; Parrish Anne-Maree; Chong Kar Hau
Documents Approved:	UOW Application Form V2 03072017 HREC Response to Review V1 03072017 A1 Letter Of Information To Parents Legal Guardians V2 03072017 A2 Consent Form For Parents Legal Guardians V2 03072017 A3 Participant Information Sheet For Children V2 03072017 A4 Letter And Consent Form For Principals V1 03072017 A5 Passive Consent Form For Parents Legal Guardians V2 03072017 B1 Verbal Script For Study Protocol V2 03072017 B2 Verbal Script For Accelerometer And Sleep Diary V2 03072017 B3 Examples Of SMS Reminder Messages V2 03072017 C1 Pubertal Developmental Scale V1 03072017 C2 Study Questionnaire V2 03072017 D Study Budget V1 03072017 C1 Study Questionnaire For Girls V1 20052017 C2 Study Questionnaire For Boys V1 20052017 C3 Sleep Diary V1 20052017

The HREC has reviewed the research proposal for compliance with the *National Statement on Ethical Conduct in Human Research* and approval of this project is conditional upon your continuing compliance with this document. Compliance is monitored through progress reports; the HREC may also undertake physical monitoring of research.

Approval is granted for a twelve month period; extension of this approval will be considered on receipt of a progress report **prior to the expiry date**. Extension of approval requires:

- The submission of an annual progress report and a final report on completion of your project.
- Approval by the HREC of any proposed changes to the protocol or investigators.
- Immediate report of serious or unexpected adverse effects on participants.
- Immediate report of unforeseen events that might affect the continued acceptability of the project.

If you have any queries regarding the HREC review process or your ongoing approval please contact the Ethics Unit on 4221 3386 or email rso-ethics@uow.edu.au.

Yours sincerely,

Associate Professor Melanie Randle
Chair, UOW & ISLHD Social Sciences
Human Research Ethics Committee

The University of Wollongong & Illawarra Shoalhaven Local Health District Social Science HREC is constituted and functions in accordance with the NHMRC National Statement on Ethical Conduct in Human Research.

Appendix 4.2 Permission letter from the New South Wales Department of Education

NSW GOVERNMENT Education Public Schools

Mr Kar-Hau Chong
University of Wollongong
Northfields Avenue
WOLLONGONG NSW 2522

DOC18/788695
SERAP 2018365

Dear Mr Chong

I refer to your application to conduct a research project in NSW government schools entitled *Understanding 24-hour movement behaviours and their associations with children's psychosocial health across the primary-secondary school transition*. I am pleased to inform you that your application has been approved.

You may contact principals of the nominated schools to seek their participation. **You should include a copy of this letter with the documents you send to principals.**

This approval will remain valid until 04-Jun-2019.

The following researcher or research assistants have fulfilled the Working with Children screening requirements to interact with or observe children for the purposes of this research for the period indicated:

Researcher name	WWCC	WWCC expires
Kar-Hau Chong	WWC1310765E	16-Aug-2022
Lucy Carolan	WWC1592905E	20-Feb-2023

I draw your attention to the following requirements for all researchers in NSW government schools:

- The privacy of participants is to be protected as per the NSW Privacy and Personal Information Protection Act 1998.
- School principals have the right to withdraw the school from the study at any time. The approval of the principal for the specific method of gathering information must also be sought.
- The privacy of the school and the students is to be protected.
- The participation of teachers and students must be voluntary and must be at the school's convenience.
- Any proposal to publish the outcomes of the study should be discussed with the research approvals officer before publication proceeds.
- All conditions attached to the approval must be complied with.

When your study is completed please email your report to: serap@det.nsw.edu.au
You may also be asked to present on the findings of your research.

I wish you every success with your research.

Yours sincerely

Elsa Lat
R/Director, School Policy and Information Management
28 August 2018

School Policy and Information Management
NSW Department of Education
Level 1, 1 Oxford Street, Darlinghurst NSW 2010 – Locked Bag 53, Darlinghurst NSW 1300
Telephone: 02 9244 5060 – Email: serap@det.nsw.edu.au

Appendix 4.3 Letter of information and consent form for school principals

LETTER OF INFORMATION TO SCHOOL PRINCIPALS

Dear Principal

We would like to invite Year 6 students at your school to participate in a research project conducted by researchers and a student pursuing a doctoral degree from the University of Wollongong. The project is entitled ***Understanding 24-hour movement behaviours and their associations with children's psychosocial health across the primary-secondary school transition***. We write to seek your approval and assistance to conduct this research.

Purpose of the research
The purpose of the research is to provide information about how children spend their time during a 24-hour period when they are asleep, sitting and being physically active. We would like to understand how the way they spend this time affects mental, social and emotional health during the transition period from primary to secondary school – a period that often coincides with changes in activity patterns, physical and psychological health.

What will participants be asked to do?
The students who chose to be involved will participate in the following activities in three phases (with 6 months in between each phase):

1. Weight and height measurements.
2. Complete paper-based questionnaires that will ask questions about changes that may be happening to their body, personal feelings and some difficulties that they might have faced over the past six months, and their current participation in sport and activities.

   A sample of the questions are provided below:
   - What would you say about the growth of your body hair?
   - How far do you agree with this statement: I worry a lot.
   - How often did you feel nervous?
   - What sort of sports and physical activities have you been involved in during the current school term?
   - How long do you spend playing on smart phone or iPad before and after school each day?

   During the second follow-up phase in Year 7 (i.e., 12 months after the first phase), they will also be asked to answer an additional question describing his/her experience with the transition to secondary school.

3. Wear a watch-like, waterproof activity device (GENEActiv) continuously for the seven-day duration to measure daily time spent sleeping, sitting and being physically active.
4. Record bedtime and waking time on a sleep log for the seven-day duration.

Are there any risks involved?
Apart from 50 minutes of student's time for the activities at school and wearing an activity device and recording bedtime and waking time for the seven-day duration, there are no risks involved. We do not expect the questionnaires to cause any harm or discomfort. However, if a student experience feelings of distress as a result of participation in this study, he/she can tell the research staff and they will provide him/her with assistance. Trained research staff with Working With Children Checks will conduct all assessments.

Benefits of the research
This research is being funded by the Faculty Seed Grant programme of University of Wollongong. The findings of this research will provide valuable information about how the way children spend time on different movement behaviours affect their overall health and wellbeing. Findings from this research will be used in a doctoral thesis, published in academic journals and presented in conferences. The research will not report on any details of an individual student or school. All information pertaining to the measures will be securely stored at the University of Wollongong and will only be accessed by the research team.

What is required of schools?
As the Principal of your school we encourage you to support your students to participate in this research project. The school will be required to distribute and collect the information sheets and consent forms to and from parents, and allow the research team to visit the school for two days in each phase to complete the assessments as described in this letter.

Withdrawal from the study
Participation in this research is voluntary and any student may decline to participate or withdraw at any time from the study without it affecting his/her relationship with the University of Wollongong in any way. Every effort will be made to protect the privacy of students. If you have inquiries about the research, please contact Kar Hau Chong by phone on (02) 4221 4274.

If you have any concerns or complaints regarding the way this research has been conducted, you can contact the UOW Ethics Officer on (02) 4221 3386 or email rso-ethics@uow.edu.au.

Yours sincerely,

Professor Anthony Okely
Chief Investigator
Faculty of Social Sciences
(02) 4221 4641
tokely@uow.edu.au

Dr Anne-Maree Parrish
Co-investigator
Faculty of Social Sciences
(02) 4221 5098
aparrish@uow.edu.au

Dr Dylan Cliff
Co-investigator
Faculty of Social Sciences
(02) 4221 5929
dylanc@uow.edu.au

Mr Kar Hau Chong
PhD Candidate
Faculty of Social Sciences
(02) 4221 4274
khc745@uowmail.edu.au

CONSENT FORM FOR SCHOOL PRINCIPALS

Research Title: Understanding 24-hour movement behaviours and their associations with children's psychosocial health across the primary-secondary school transition

Researchers: Professor Anthony Okely, Dr Anne-Maree Parrish, Dr Dylan Cliff, Kar Hau Chong

I have been given information about the above entitled research, which is part of a PhD project for Kar Hau Chong supervised by Professor Anthony Okely, Dr Anne-Maree Parrish and Dr Dylan Cliff in the Faculty of Social Sciences at the University of Wollongong. I understand that the data collected will be used to provide information about how children spend their time during a 24-hour period when they are asleep, sitting and being physically active, and whether how the way they spend this time affects mental, social and emotional health over the transition period from primary to secondary school.

I have been advised of the potential risks and burdens associated with this research. I have had an opportunity to ask the researcher any further questions I may have had about the research. I understand that the research will be fully explained prior to its implementation and that I will be able to ask questions about its delivery at that time. I understand that my student's participation in this research is voluntary and they can withdraw from the study at any time without it affecting their relationship with the University of Wollongong in any way.

I am aware that if I have enquiries about the research, I can contact Kar Hau Chong on (02) 4221 4274. If I have any concerns or complaints regarding the way this research has been conducted, I can contact the UOW Ethics Officer, Social Sciences Human Research Ethics Committee of the University of Wollongong on (02) 4221 3386 or email rso-ethics@uow.edu.au.

By signing below I give permission to participate in this research.

_____ Date: _____

Signature

Name: _____

School: _____

Appendix 4.4 Letter of information and active consent form for parents/legal guardians

LETTER OF INFORMATION TO PARENTS/LEGAL GUARDIANS

Dear Parent/Legal Guardian

Your child is invited to participate in a research project conducted by researchers and a student pursuing a doctoral degree from the University of Wollongong. The project is entitled *Understanding 24-hour movement behaviours and their associations with children's psychosocial health across the primary-secondary school transition*. We write to seek your approval and assistance to conduct this research and to involve your child as a participant.

Purpose of the research

The purpose of the research is to provide information about how children spend their time during a 24-hour period when they are asleep, sitting and being physically active. We would like to understand how the way they spend this time affects mental, social and emotional health during the transition period from primary to secondary school – a period that often coincides with changes in activity patterns, physical and psychological health.

Investigators

Professor Anthony Okely
Chief Investigator
Faculty of Social Sciences
(02) 4221 4641
tokely@uow.edu.au

Dr Anne-Maree Parrish
Co-investigator
Faculty of Social Sciences
(02) 4221 5098
aparrish@uow.edu.au

Dr Dylan Cliff
Co-investigator
Faculty of Social Sciences
(02) 4221 5929
dylanc@uow.edu.au

Mr Kar Hau Chong
PhD Candidate
Faculty of Social Sciences
(02) 4221 4274
khc745@uowmail.edu.au

What will participants be asked to do?

The data collection will be completed at school by trained research staff with valid Working With Children Checks during a normal school day. If you agree for your child to participate in this research, he/she will be asked to take part in the following activities in three phases (with 6 months in between each phase):

1. Weight and height measurements (Day-1).
2. Complete paper-based questionnaires that will ask questions about changes that may be happening to his/her body, personal feelings and some difficulties that he/she might have faced over the past six months, and his/her current participation in sport and activities. (Day-1).

   A sample of the questions are provided below:
   - What would you say about the growth of your body hair?
   - How far do you agree with this statement: I worry a lot.

- How often did you feel nervous?
- What sort of sports and physical activities have you been involved in during the current school term?
- How long do you spend playing on smart phone or iPad before and after school each day?

During the second follow-up phase in Year 7 (i.e., 12 months after the first phase), your child will also be asked to answer an additional question describing his/her experience with the transition to secondary school.

3. Wear a watch-like, waterproof activity device (GENEActiv) continuously for seven days (morning of Day-1 till morning of Day-8; including bathing or swimming time) to measure daily time spent sleeping, sitting and being physically active.
4. Record his/her bedtime and waking time on a provided activity monitor log for seven consecutive days (Day-1 to Day-7).

During the activity monitoring period (Day-2 to Day-7), a standardised SMS reminder message will be sent to your child's/your mobile phone every morning to remind him/her to wear the activity device and record bedtime and waking time on the activity monitor log. On Day-8, another SMS reminder message will be sent to remind your child to bring the activity device and activity monitor log to school and return them to the research staff.

Are there any risks involved?

Apart from 50 minutes of your child's time for the activities at school (Day-1) and wearing an activity device and recording bedtime and waking time for the seven-day duration, there are no risks involved. We do not expect the questionnaires to cause any harm or discomfort. However, if your child experience feelings of distress as a result of participation in this study, he/she can tell the research staff and they will provide him/her with assistance. Trained research staff with Working With Children Checks will conduct all assessments. Your child's involvement in the study is voluntary and he/she may withdraw for any reason, at any time from the study and withdraw any data that has provided to that point. If your child wish to withdraw from the study, please contact Kar Hau Chong by phone on (02) 4221 4274.

Benefits of the research

This research is funded by the Faculty Seed Grant of University of Wollongong. This research will provide valuable information about how the way children spend time on different movement behaviours affect their overall health and wellbeing. Results of this research will be used in a doctoral thesis and published in academic journals or presented in conferences. In the reporting of results, all aspects of your child's information will remain confidential and he/she will not be identified in any part of the research. All information pertaining to the measures will be securely stored at the University of Wollongong and will only be accessed by the research team.

If you agree for your child to participate in this research, please sign and complete the demographic questions (child's sex, date of birth, cultural background and home postcode) on the consent form attached and send it back to your child's classroom teacher.

Ethics review and complaints

This study has been reviewed by the Social Sciences Human Research Ethics Committee of the University of Wollongong. If you have any concerns or complaints regarding the way this research has been conducted, you can contact the UOW Ethics Officer on (02) 4221 3386 or email rso-ethics@uow.edu.au.

Thank you for your interest in this study.

CONSENT FORM FOR PARENTS/LEGAL GUARDIANS

Research Title: Understanding 24-hour movement behaviours and their associations with children's psychosocial health across the primary-secondary school transition

Researchers: Professor Anthony Okely, Dr Anne-Maree Parrish, Dr Dylan Cliff, Kar Hau Chong

I have been given information about the above entitled research, which is part of a PhD project for Kar Hau Chong supervised by Professor Anthony Okely, Dr Anne-Maree Parrish and Dr Dylan Cliff in the Faculty of Social Sciences at the University of Wollongong. I understand that the data collected will be used to provide information about how children spend their time during a 24-hour period when they are asleep, sitting and being physically active, and whether how the way they spend this time affects mental, social and emotional health over the transition period from primary to secondary school.

I understand that, if I consent to my child participating in this project, he/she will be asked to involve in the following activities in three phases (with 6 months in between each phase):

1. Weight and height measurements.
2. Complete paper-based questionnaires that will ask questions about changes that may be happening to his/her body, personal feelings and some difficulties that he/she might have faced over the past six months, and his/her current participation in sport and activities [and an additional question describing his/her experience with the transition to secondary school during the second follow-up phase in Year 7 (i.e., 12 months after first visit)].
3. Wear an activity device (GENEActiv) and record bedtime and waking time for the seven-day duration.

I understand that I, as the parent/legal guardian, will be asked to do the following:

1. Provide demographic information such as my child's sex, date of birth, cultural background, and home postcode for the purpose of data analysis by completing questions at the end of this consent form.

I have been advised of the potential risks and burdens associated with this research. I have had an opportunity to ask the researcher any questions I may have about the research and my child's participation.

I understand that my child's participation in this research is voluntary; this means that he/she is free to refuse to participate and is free to withdraw from the research at any time.

I am aware that if I have enquiries about the research or my child wish to withdraw from the study, I can contact Kar Hau Chong on (02) 4221 4274. If I have any concerns or complaints regarding the way this research has been conducted, I can contact the UOW Ethics Officer, Social Sciences Human Research Ethics Committee of the University of Wollongong on (02) 4221 3386 or email rso-ethics@uow.edu.au.

By signing below I am indicating my consent for my child _____ to participate in the research. I understand that the data collected from my child will be used for primarily for a doctoral thesis, and also will be used in summary form for conference presentations and journal publications, and I consent for it to be used in that manner. I understand that any individual data about my child will not be published.

I hereby consent to my child _____ from

_____ (School), _____ (Class) participating in the study "Understanding 24-hour movement behaviours and their associations with children's psychosocial health across the primary-secondary school transition", conducted by the University of Wollongong. My child has indicated their consent by signing below.

_____ Date: _____
Signature of Parent/Guardian

Name of parent/guardian: _____

_____ Date: _____
Signature of Child

Name of child: _____

Please complete the following details:
Sex of the child: ☐ Male ☐ Female

Date of birth: _____ Day _____ Month _____Year

Cultural background: _____ Home postcode: _____

Mobile phone number *(For SMS reminders purpose)*:
☐ Parent: _____ ☐ Child: _____

What is your preferred method of contact for the delivery of consent form during follow-up phases?
☐ Postage *(Please provide your residential address:*

_____*)*

☐ Email *(Please provide your email address:* _____*)*

Appendix 4.5 Letter of information for children

PARTICIPANT INFORMATION SHEET FOR CHILDREN

Dear Student

This is an invitation for you to participate in a study conducted by researchers at the University of Wollongong. The research is called *Understanding 24-hour movement behaviours and their associations with children's psychosocial health across the primary-secondary school transition*.

What is this research about?
This research will help is to understand how young people like you spend time sleeping, sitting and being physically active during a 24-hour period. We would also like to understand how the way you spend this time affects your personal feelings and emotions when you make the transition from primary to secondary school.

Who is conducting the study?
These are the people from the university involved in this study:

Professor Anthony Okely
Chief Investigator
Faculty of Social Sciences
(02) 4221 4641
tokely@uow.edu.au

Dr Anne-Maree Parrish
Co-investigator
Faculty of Social Sciences
(02) 4221 5098
aparrish@uow.edu.au

Dr Dylan Cliff
Co-investigator
Faculty of Social Sciences
(02) 4221 5929
dylanc@uow.edu.au

Mr Kar Hau Chong
PhD Candidate
Faculty of Social Sciences
(02) 4221 4274
khc745@uowmail.edu.au

What we would like you to do
If you agree to participate in this study, you will be asked to take part in the following activities on three separate occasions (with 6 months in between each occasion):

5. Weight and height measurements (Day-1).
6. Complete paper-based questionnaires that will ask you questions about changes that may be happening to your body, your personal feelings and some difficulties that you might have faced over the past six months and your current participation in sport and activities (Day-1).
   A sample of the questions are provided below:
   - What would you say about the growth of your body hair?
   - How far do you agree with this statement: I worry a lot.
   - How often did you feel nervous?
   - What sort of sports and physical activities have you been involved in during the current school term?

- How long do you spend playing on smart phone or iPad before and after school each day?

During the third occasion in Year 7 (i.e., 12 months after the first occasion), you will also be asked to answer an additional question describing your experience with the transition to secondary school.

7. Wear a watch-like, waterproof activity device (GENEActiv) continuously for seven days (morning of Day-1 till morning of Day-8; including bathing or swimming time) to measure your time spent sleeping, sitting and being physically active.
8. Record your bedtime and waking time on a provided activity monitor log for seven consecutive days (Day-1 to Day-7).

During the activity monitoring period (Day-2 to Day-7), a standardised SMS reminder message will be sent to your/your parent's mobile phone every morning to remind you to wear the activity device and record bedtime and waking time on the activity monitor log. On Day-8, another SMS reminder message will be sent to remind you to bring the activity device and activity monitor log to school and return them to the research staff.

Are there any risks involved?

Apart from 50 minutes of your time for the activities at school (Day-1) and wearing an activity device and recording bedtime and waking time for the seven-day duration, there are no risks involved. We do not expect the questionnaires to cause any harm or discomfort. However, if you experience feelings of distress as a result of participation in this study, you can tell the research staff and they will provide you with assistance. You are free to decide if you want to be involved in this research or not, and you can stop participating at any time and any information you have given will not be used. If you wish to withdraw from the research, please tell your parents or the teacher who can contact Kar Hau Chong on (02) 4221 4274.

Benefits of the research

This research is funded by the Faculty Seed Grant of University of Wollongong. This research will provide valuable information about how the way young people like you spend time on different movement behaviours affect overall health and wellbeing. Results of this research will be used in a doctoral thesis and published in academic journals or presented in conferences. In the reporting of results your information will remain confidential and we will not use your name in any part of the research. All information pertaining to the measures will be securely stored at the University of Wollongong and will only be accessed by the research team.

How can you sign up for the research?

If you agree to participate in this research, please inform your parents or legal guardians that they would need to sign the consent form attached and send it back to your classroom teacher.

Ethics review and complaints

This research has been reviewed by the Social Sciences Human Research Ethics Committee of the University of Wollongong. If you are not happy with the way this research has been conducted, you can tell your parents or the teacher who can contact the University Ethics Officer on (02) 4221 3386 or email rso-ethics@uow.edu.au.

Thank you for your interest in this study.

Appendix 4.6 Passive consent form for parents/legal guardians at follow-up phases

PASSIVE CONSENT FORM FOR PARENTS/LEGAL GUARDIANS

Dear Parent/Guardian

Thank you for your initial agreement for your child to participate in our research project titled *Understanding 24-hour movement behaviours and their associations with children's psychosocial health across the primary-secondary school transition*. The purpose of the research is to provide information about how children spend their time during a 24-hour period when they are asleep, sitting and being physically active. We would like to understand how the way they spend this time affects mental, social and emotional health during the transition period from primary to secondary school – a period that often coincides with changes in activity patterns, physical and psychological health.

We appreciate your child's cooperation and effort in completing the data collection activities during the first phase of the study (*insert date of data collection day at baseline*). We would like to seek your permission for your child to continue participating in the *(insert second or third)* phase of the study, which is expected to commence in *(insert the month of data collection)* at the school.

If you do not wish your child to participate in the *(insert second or third)* phase of the study, please contact Kar Hau Chong by phone on (02) 4221 4274 or email khc745@uowmail.edu.au If we do not hear from you by *(insert date – one month before data collection)*, we will assume your child has permission to continue participating in this study.

If you agree for your child to participate in the *(insert second or third)* phase of the study, he/she will be asked to take part in the following data collection activities, which will be completed at school by trained research staff with valid Working With Children Checks during a normal school day:

1. Height and weight measurements (Day-1).
2. Complete paper-based questionnaires that will ask questions about changes that may be happening to his/her body, personal feelings and some difficulties that he/she might have faced over the past six months, and his/her current participation in sport and activities. (Day-1).

   A sample of the questions are provided below:
   - What would you say about the growth of your body hair?
   - How far do you agree with this statement: I worry a lot.
   - How often did you feel nervous?
   - What sort of sports and physical activities have you been involved in during the current school term?
   - How long do you spend playing on smart phone or iPad before and after school each day?

During the second follow-up phase (i.e., 12 months after the first phase), your child will repeat this questionnaire and also be asked to answer an additional question describing his/her experience with the transition to secondary school.

3. Wear a watch-like, waterproof activity device (GENEActiv) continuously for seven days (morning of Day-1 till morning of Day-8; including bathing or swimming time) to measure daily time spent sleeping, sitting and being physically active.
4. Record his/her bedtime and waking time on a provided activity monitor log for seven consecutive days (Day-1 to Day-7).

During the activity monitoring period (Day-2 to Day-7), a standardised SMS reminder message will be sent to your child's/your mobile phone every morning to remind him/her to wear the activity device and record bedtime and waking time on the activity monitor log. On Day-8, another standardised SMS reminder message will be sent to remind your child to bring the activity device and activity monitor log to school and return them to the research staff.

Apart from 50 minutes of your child's time for the activities at school (Day-1) and wearing an activity device and recording bedtime and waking time for the seven-day duration, there are no risks involved. We do not expect the questionnaires to cause any harm or discomfort. However, if your child experience feelings of distress as a result of participation in this study, he/she can tell the research staff and they will provide him/her with assistance. Your child's involvement in the study is voluntary and he/she may withdraw for any reason, at any time from the study and withdraw any data that has provided to that point. In the reporting of results, all aspects of your child's information will remain confidential and he/she will not be identified in any part of the research. All information pertaining to the measures will be securely stored at the University of Wollongong and will only be accessed by the research team.

If you have any questions or concerns about this study, please do not hesitate to contact us at any time.

Sincerely,

Professor Anthony Okely
Chief Investigator
Faculty of Social Sciences
(02) 4221 4641
tokely@uow.edu.au

Dr Anne-Maree Parrish
Co-investigator
Faculty of Social Sciences
(02) 4221 5098
aparrish@uow.edu.au

Dr Dylan Cliff
Co-investigator
Faculty of Social Sciences
(02) 4221 5929
dylanc@uow.edu.au

Mr Kar Hau Chong
PhD Candidate
Faculty of Social Sciences
(02) 4221 4274
khc745@uowmail.edu.au

Appendix 4.7 Study questionnaires used in Survey 1

STUDY QUESTIONNAIRE

Research Title: Understanding 24-hour movement behaviours and their associations with children's psychosocial health across the primary-secondary school transition

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PARTICIPANT ID *(for office use)* ☐

DATE OF SURVEY *(for office use)* ☐

Thank you for agreeing to participate in our study. By completing this questionnaire, you will help us understand more about health and activity patterns of young people like yourself. Your answers are confidential and will only be seen by the research team.

HOW TO COMPLETE THIS QUESTIONNAIRE:
Please use a BALLPOINT PEN or a DARK PENCIL to fill in this form. There are no right and wrong answers --- this is not a test. Please take your time to read and answer all the questions as honestly and accurately as you can.

---

1. For each of the following question, please place a cross (✕) in the box for Not True, Somewhat True or Certainly True. It would help us if you answered all questions as best you can even if you are not absolutely certain or the question seems strange! Please give your answers on the basis of how things have been for you **over the last six months.**

	Not True	Somewhat True	Certainly True
I try to be nice to other people. I care about their feelings			
I am restless, I cannot stay still for long			
I get a lot of headaches, stomach-aches or sickness			
I usually share with others (food, games, pens etc.)			
I get very angry and often lose my temper			
I am usually on my own. I generally play alone or keep to myself			
I usually do as I am told			
I worry a lot			
I am helpful if someone is hurt, upset or feeling ill			

	Not True	Somewhat True	Certainly True
I am constantly fidgeting or squirming			
I have one good friend or more			
I fight a lot. I can make other people do what I want			
I am often unhappy, down-hearted or tearful			
Other people my age generally like me			
I am easily distracted, I find it difficult to concentrate			
I am nervous in new situations. I easily lose confidence			
I am kind to younger children			
I am often accused of lying or cheating			
Other children or young people pick on me or bully me			
I often volunteer to help others (parents, teachers, children)			
I think before I do things			
I take things that are not mine from home, school or elsewhere			
I get on better with adults than with people my own age			
I have many fears, I am easily scared			
I finish the work I'm doing. My attention is good			

2. When answering the following questions, think about how you have been feeling <u>over the past 30 days.</u> Please place a cross (X) in the box that best represents how you have been feeling.

	None of the time	A little of the time	Some of the time	Most of the time	All of the time
How often did you feel tired out for no good reason?					
How often did you feel nervous?					
How often did you feel so nervous that nothing could calm you down?					
How often did you feel hopeless?					
How often did you feel restless or fidgety?					
How often did you feel so restless you could not sit still?					
How often did you feel depressed?					
How often did you feel that everything was an effort?					
How often did you feel so sad that nothing could cheer you up?					

	None of the time	A little of the time	Some of the time	Most of the time	All of the time
How often did you feel worthless?					

The next two questions ask about bullying. Bullying is when people tease, threaten, spread rumours about, hit, shove, or hurt other people over and over again. Cyber bullying is when people use mobile phones or the internet to send nasty or threatening emails or messages, post mean or nasty comments or pictures on websites like Facebook, or have someone pretend to be them online to hurt other people over and over again. It is not bullying when two people of about the same strength or power argue or fight or tease each other in a friendly way.

3. **In the last 6 months,** how often were you bullied or cyber bullied? (Cross one box only)
   - ☐ I was not bullied in the last 6 months
   - ☐ Once or twice in the last 6 months
   - ☐ I was bullied every few months
   - ☐ I was bullied every few weeks
   - ☐ I was bullied about once a week
   - ☐ I was bullied most days

4. **In the last 6 months,** how often did you bully or cyber bully someone? (Cross one box only)
   - ☐ I did not bully others in the last 6 months
   - ☐ Once or twice in the last 6 months
   - ☐ Every few months
   - ☐ Every few weeks
   - ☐ About once a week
   - ☐ Most days

5. What sort of sports and physical activities did you participate in **over the last 3 months**? (Please place a cross (X) in the appropriate boxes).

	Yes	No
Competitive team sports - at school *(e.g. football, cricket, netball, basketball)*		
Competitive team sports - outside school *(e.g. football, cricket, netball, basketball)*		
Competitive individual sports - at school *(e.g. tennis, karate/martial arts, gymnastics, swimming, track and field)*		
Competitive individual sports - outside school *(e.g. tennis, karate/martial arts, gymnastics, swimming, track and field)*		
Organised but non-competitive physical activity *(e.g. aerobics, weights class, circuit training, dancing)*		

6. Overall, you have approximately 8 hours of free time before and after school, some of which is spent sitting. You may do multiple activities at the same time (for example, play on a smartphone while sitting in front of the TV), so please estimate how much time was spent on **each** activity within the total time spent doing both (for example, if you were watching TV and using your smartphone over a period of one hour, you may have spent 20 minutes mostly focusing on your smartphone and 40 minutes mostly focusing on the TV).

   Keeping this in mind, think about a **normal school week**, and write down how long you spend doing the following activities **before and after school each day**. Leave blank if you do not do that activity.

Activity	Monday		Tuesday		Wednesday		Thursday		Friday	
	Hours	Mins	Hours	Mins	Hours	Mins	Hours	Mins	Hours	Mins
Watching TV (including videos/DVDs)										
Using a computer/laptop for entertainment *(e.g. watching videos/movies/YouTube, listening to music, surfing the net)*										
Using a smartphone/tablet (e.g. iPad) for entertainment *(e.g. watching videos/YouTube, listening to music, surfing the net)*										
Using any screen devices for social purposes *(e.g. text/instant messaging, Facebook, Instagram, Snapchat, Tumblr, Twitter)*										
Playing computer/video games *(e.g. Nintendo, Xbox, Playstation, Wii)*										
Using a computer/laptop/tablet (e.g. iPad) for doing homework or other educational activities										
Doing homework not on the computer/laptop/tablet (e.g. iPad)										
Reading for fun										
Being tutored										

Activity	Monday		Tuesday		Wednesday		Thursday		Friday	
	Hours	Mins	Hours	Mins	Hours	Mins	Hours	Mins	Hours	Mins
Travel *(in car/bus/train/boat)*										
Doing crafts or hobbies *(including board or card games)*										
Sitting around *(chatting with friends/on the phone/chilling)*										
Playing/practising a musical instrument while sitting										

7. Overall, you have approximately 16 hours of free time on a weekend day, some of which is spent sitting. You may do multiple activities at the same time (for example, play on a smartphone while sitting in front of the TV), so please estimate how much time was spent on **each** activity within the total time spent doing both (for example, if you were watching TV and using your smartphone over a period of one hour, you may have spent 20 minutes mostly focusing on your smartphone and 40 minutes mostly focusing on the TV).

   Keeping this in mind, think about **a normal weekend,** and write down how long you spend doing the following activities **each weekend day**. Leave blank if you do not do that activity.

Activity	Saturday		Sunday	
	Hours	Mins	Hours	Mins
Watching TV (including videos/DVDs)				
Using a computer/laptop for entertainment *(e.g. watching videos/movies/YouTube, surfing the net)*				
Using a smartphone/tablet (e.g. iPad) for entertainment *(e.g. watching videos/YouTube, listening to music)*				
Using any screen devices for social purposes *(e.g. text/instant messaging, Facebook, Instagram, Snapchat, Tumblr, Twitter)*				
Playing computer/video games *(e.g. Nintendo, Xbox, Playstation, Wii)*				
Using a computer/laptop/tablet (e.g. iPad) for doing homework or other educational activities				
Doing homework not on the computer/laptop/tablet (e.g. iPad)				
Reading for fun				
Being tutored				
Travel *(in car/bus/train/boat)*				
Doing crafts or hobbies *(including board or card games)*				

Activity	Saturday		Sunday	
	Hours	Mins	Hours	Mins
Sitting around *(chatting with friends/on the phone/chilling)*				
Playing/practising a musical instrument while sitting				
Sitting while attending religious/cultural activities? *(e.g. going to church/temple/mosque or Saturday/Sunday school)*				

8. How would you rate your transition experience from primary to secondary school (Year 6 → Year 7)? (Cross one box only)

☐ Difficult ☐ Somewhat difficult ☐ Somewhat easy ☐ Easy

PUBERTAL DEVELOPMENTAL SCALE FOR BOYS

The following questions are about changes that may be happening to your body. These changes normally happen to different young people at different ages. Please place a cross (X) in one box only that best describes what is happening to you.

1. Would you say that your growth in height:
   - ☐ Has not yet started
   - ☐ Has barely started
   - ☐ Has definitely started
   - ☐ Seems completed

2. And how about the growth of your body hair? Would you say that your body hair growth:
   - ☐ Has not yet started
   - ☐ Has barely started
   - ☐ Has definitely started
   - ☐ Seems completed

3. Have you noticed any skin changes, especially pimples?
   - ☐ Has not yet started
   - ☐ Has barely started
   - ☐ Has definitely started
   - ☐ Seems completed

4. Have you noticed that a deepening of your voice?
   - ☐ Has not yet started
   - ☐ Has barely started
   - ☐ Has definitely started
   - ☐ Seems completed

5. Have you begun to grow hair on your face?
   - ☐ Has not yet started
   - ☐ Has barely started
   - ☐ Has definitely started
   - ☐ Seems completed

PUBERTAL DEVELOPMENTAL SCALE FOR GIRLS

The following questions are about changes that may be happening to your body. These changes normally happen to different young people at different ages. Please place a cross (✕) in one box only that best describes what is happening to you.

1. Would you say that your growth in height:
   - ☐ Has not yet started
   - ☐ Has barely started
   - ☐ Has definitely started
   - ☐ Seems completed

2. And how about the growth of your body hair? Would you say that your body hair growth:
   - ☐ Has not yet started
   - ☐ Has barely started
   - ☐ Has definitely started
   - ☐ Seems completed

3. Have you noticed any skin changes, especially pimples?
   - ☐ Has not yet started
   - ☐ Has barely started
   - ☐ Has definitely started
   - ☐ Seems completed

4. Have you noticed that your breasts have begun to grow?
   - ☐ Has not yet started
   - ☐ Has barely started
   - ☐ Has definitely started
   - ☐ Seems completed

5. Have you begun to menstruate (started to have you period)?
   - ☐ Yes
   - ☐ No

   b) If yes, how old were you when you started to menstruate? _____ years

Appendix 4.8 An image of the GENEActiv accelerometer used in Survey 1

Source: https://www.activinsights.com/actigraphy/geneactiv-original/

Appendix 4.9 Comparison of sedentary activity items from the Adolescent Sedentary Activity Questionnaire (ASAQ) (Hardy et al. 2016) with the adapted version used in Survey 1 by activity domains

Original activity items in ASAQ	Activity items used in Survey 1
Recreational screen time	
Watching TV Watching videos/DVDs	Watching TV (including videos/DVDs)
Using the computer for fun	Using a computer/laptop for entertainment (e.g. watching videos/movies/YouTube, listening to music, surfing the net)
Playing on smart phone or iPad	Using a smartphone/tablet (e.g. iPad) for entertainment (e.g. watching videos/YouTube, listening to music, surfing the net)
Playing computer or video games (Nintendo, Xbox, PlayStation, Wii)	Playing computer or video games (Nintendo, Xbox, PlayStation, Wii) Using any screen devices for social purposes (e.g. text/instant messaging, Facebook, Instagram, Snapchat, Tumblr, Twitter)[a]
Out-of-school educational activities	
Using the computer for doing homework	Using a computer/laptop/tablet (e.g. iPad) for doing homework or other educational activities
Doing homework not on the computer	Doing homework not on the computer/laptop/tablet (e.g. iPad)
Being tutored	Being tutored
Social activities	
Sitting around (chatting with friends/on the phone/chilling)	Sitting around (chatting with friends/on the phone/chilling)
Going to church or Saturday school[b]	Attending religious/cultural activities (e.g. going to church/temple/mosque or Saturday/Sunday school)[b]
Passive travel	
Travel (car/bus/train)	Travel (in car/bus/train/boat)
Cultural activities	
Reading for fun	Reading for fun
Doing crafts or hobbies	Doing crafts or hobbies (including board or card games)
Playing/practising a musical instrument	Playing/practising a musical instrument

[a] This item was added to reflect current trends in children's use of screen media.

[b] This item was only included in the activity list for weekend days.

Appendix 4.10 Comparison of the original survey items from the FITGALS study (Eime et al. 2016) with the adapted version used in Survey 1

Original survey items (Eime et al. 2016)	Adapted version used in Survey 1
What sort of sports and physical activities do you participate in *this year and last year*? (Yes/No option) • PE classes • Competitive team sports – at school • Competitive team sports – outside school • Competitive individual sports – at school • Competitive individual sports – outside school • Organised but non-competitive physical activity • Non-organised physical activity	What sort of sports and physical activities did you participate in *over the last 3 months*? (Yes/No option) • Competitive team sports – at school • Competitive team sports – outside school • Competitive individual sports – at school • Competitive individual sports – outside school • Organised but non-competitive physical activity

Appendix 4.11 Approval for the access to LSAC dataset (Survey 2)

From: ada@anu.edu.au
To: Kar-Hau Chong
Subject: ADA Dataverse: You have been granted access to dataset: "Growing Up in Australia: Longitudinal Study of Australian Children (LSAC) Release 7.1 (Waves 1-7)>"
Date: Friday, 19 July 2019 2:18:58 AM

Hello,

You recently applied for access to controlled access files in dataset: Growing Up in Australia: Longitudinal Study of Australian Children (LSAC) Release 7.1 (Waves 1-7). We are pleased to advise that your application for access has been approved.

Your obligations as an Authorised Data User are contained in the Terms and Conditions of Use.

You can now view and download files from the dataset at this link: https://dataverse.ada.edu.au/dataset.xhtml?persistentId=doi:10.26193/F2YRL5.

(Please note that you will need to login to Dataverse to see your updated access, and to download controlled access files.)

If you have any queries in relation to the data please refer to the supporting documentation for Growing Up in Australia: Longitudinal Study of Australian Children (LSAC) Release 7.1 (Waves 1-7), or click on the email icon from anywhere in Dataverse to submit a query.

Thank you,
The Australian Data Archive
on behalf of the data owner(s): Department of Social Services (Australian Government); Australian Institute of Family Studies (Australian Government); Australian Bureau of Statistics (Australian Government).

Appendix 5.1 Compositional variation matrix of 24-hour movement behaviour composition at primary (T1) and secondary school (T2) time points stratified by day type

Mean variation of the pairwise log-ratios	Overall daily		Weekdays		Weekends	
	T1	T2	T1	T2	T1	T2
Sleep – SED	0.027	0.028	0.034	0.030	0.057	0.059
Sleep – LPA	0.038	0.034	0.037	0.036	0.122	0.105
Sleep – MVPA	0.150	0.183	0.157	0.361	0.412	0.429
SED – LPA	0.060	0.053	0.059	0.049	0.170	0.150
SED – MVPA	0.218	0.234	0.232	0.423	0.531	0.552
LPA – MVPA	0.129	0.146	0.135	0.316	0.253	0.275

A value closer to zero indicates higher co-dependency between the two behaviours.
SED=sedentary time; LPA=light-intensity physical activity; MVPA=moderate- to vigorous-intensity physical activity.

Appendix 6.1 Data checking and cleaning procedures for time-use diaries

Step	Description of the procedure	Decision(s) made
1	Check for the recording period of each diary (i.e., the difference between the start time of the first and last recorded activities) and determine if it was a 'complete-day' diary.	• A diary was excluded if it had ≤ 12 hours of activities recorded as it was likely to be an incomplete diary record. This was also done to avoid unrealistically long time being allocated to a particular activity when forming the 24-h time-use composition.
2	Check for missing or improbable wake-up and go-to-bed/sleep times by considering the start time of the first and last activities recorded in the diary. Reason: Wake-up and go-to-bed/sleep times were recorded in a separate location to the diary activities. There were cases where these times were misaligned with the diary activities (e.g., a child might have reported a wake-up time which was later than the start time of their first diary activity).	• A diary was excluded if 1) the wake-up or go-to-bed/sleep times was recorded before 4:00AM and 12:00PM, respectively; and/or 2) it had undefined activity times recorded between midnight and wake-up times. • If the start time of the first recorded activity (must be after 4:00AM) was the same as or before the wake-up time, wake-up time was recoded to start one second before the start time of the first activity. This meant that the first recorded activity was not "overwritten" by the wake-up time. • If the start time of the last recorded activity was the same as or after the go-to-bed/sleep time (must be after 12:00PM), go-to-bed/sleep time was recoded to start one second after the start time of the last activity. This meant that bed and/or sleep time was not "overwritten" by the last recorded activity (which would then have extended its duration to midnight). It also meant that this last activity was ascribed a duration of only one second, later rounded to zero.
3.	Check if there was any recorded activity with unexceptionally long duration (calculated as the difference between the start time of the particular activity and the start time of the following activity) or any undefined activity time.	• Any episodes of eating/drinking that lasted longer than 15 minutes were recoded by assigning the excess time to the predicting activity (provided that it was not eating/drinking). This was done to avoid overestimating the time spent in eating/drinking, which often co-occur with other activities in this age group. • All undefined activity times (e.g., the time between wake-up time and the start time of the first activity) were classified as 'Unknown'.

Appendix 6.2 List of time-use diary activities for constructing the 24-hour domain-specific movement behaviour composition at primary (T1) and secondary school (T2) time points

Domains	Activity codes at Wave 4 (T1)	Activity codes at Wave 5 (T2)
Self-care/Domestic	Eating/drinking Personal/Health care Bathing, dressing, toileting, teeth brushing, hair care etc. Getting self ready, packing own school or sports bag Dentist, Doctor, Chiropractor, Physio etc. Making, preparing own food Cooking, meal preparation, making lunch, setting table for others Washing dishes, stacking and emptying dishwasher Taking care of siblings, other children Taking care of pets Shopping Chores	Eating/drinking Cleaning teeth Showering/bathing Getting dressed / getting ready Personal care nec. Doctor Dentist Physiotherapist / Chiropractor Medical/Health care nec. Laundry/clothes care Babysitting Food/drink preparation Food/drink clean up Animal care ('Chores' category, excluding active play) Home maintenance Taking care of siblings Chores nec. Shopping Retailing (including fast food) Animal care ('Work' category) Working in a family business or farm Work nec. Volunteering
Physical Activity	Organised team sports and training i.e fooball, basketball, netball etc. Organised individual sport i.e. swimming, dancing, martial arts, etc. Ball games, riding a bike, scooter, skateboard, skipping, running, games and other free activities By foot By bike, scooter, skateboard etc. Active activities Making own bed, tidying own room Cleaning, tidying other rooms Gardening, putting out the bin Taking pet for walk	Organised team sports and training Organised individual sport and training Unstructured active play By foot By bike, scooter, skateboard etc. Active club activities Active activities nec Pamphlet delivering Umpiring/refereeing Car washing Gardening / lawn mowing ('Work' category) Gardening / lawn mowing ('Chores' category) Cleaning/tidying Walking pets / playing with pets
Social Time	Scouts, girl guides, cadets, youth groups Going to church, museums, cultural events, fairs, community events	Going out to a concert, play, museum, art gallery, community or school event , an amusement park etc.

	Non-Active Club Activities i.e. Chess Club Going to live sporting events Communication Talking face to face Talking on a landline phone Talking on a mobile phone	Religious activities / ritual ceremonies Non-active club activities Non-verbal interaction (e.g. cuddles) Attending live sporting events Talking face-to-face (in person not via electronic devices) Talking on a landline phone (not video chat) Talking on a mobile phone (not video chat) Communication nec.
Education	School lessons Private music, language or religion lessons, tutoring Homework (not on computer) including music practise Computer for homework - internet Computer for homework - not internet	School lessons Private music lessons/practice, academic tutoring Doing homework (not via electronic devices) Doing homework
Screen Time	Electronic media/Games/Computer use Computer games - internet Computer games - not internet Xbox, Playstation, Nintendo, WII etc TV/DVD Cinema Texting, email, social networking - Facebook or twitter Skype or Webcam Internet not covered elsewhere	Playing games Creating/maintaining websites (excluding social networking profile) Watching TV programs or movies/videos Spending time on social networking sites Texting/emailing Online chatting / Instant messaging Video chatting (e.g. Skype) Internet shopping (excluding downloading/posting media) General Internet browsing (excluding homework) General application use (e.g. Microsoft Office; excluding homework) Electronic device use nec. Downloading/posting media (e.g. music, videos, applications)
Quiet Time	Listening to music, CDs, playing music for leisure Reading or being read to for leisure Board or card games, puzzles, toys, art and craft, etc. Doing nothing Non-active activities	Listening to music Reading or being read to for leisure Playing musical instruments or singing for leisure Filling out the diary Unstructured non-active play Non-active activities nec. Doing nothing

Sleep	Sleeping/napping	Sleeping/napping (not end of day bed-time)
Passive Transport	By private car Travel by public transport such as bus, taxi or aeroplane Travel	By private motor vehicle/bike By public/chartered transport such as bus, taxi or aeroplane Travel nec.

Note. At Wave 5 (T2), several changes were made to the activity coding framework, including the disaggregation of certain activities to allow for a more detailed description of activities, and the addition of the 'work' category to reflect age-appropriate development (i.e., involve in employment-type activities) (Corey et al. 2014).

Appendix 6.3 Descriptive information about the presence of zero values in movement behaviour data at each time point

Domains	T1	T2
Self-care/Domestic	2 (0.2%)	0 (0%)
Physical Activity	68 (7.5%)	121 (13.3%)
Social	469 (51.6%)	357 (39.3%)
Education	220 (24.2%)	236 (26.0%)
Recreational Screen Use	93 (10.2%)	61 (6.7%)
Quiet Time	289 (31.8%)	362 (39.8%)
Sleep	0 (0%)	0 (0%)
Passive Transport	107 (11.8%)	123 (13.5%)

Note. The values presented as the number of participants (% of the overall sample) who recorded zero minute in the specific movement behaviour domain.

Appendix 6.4 Compositional variation matrix of the 24-hour domain-specific movement behaviour composition at primary (T1) and secondary school (T2) time points

a) School day sample (n=613)

Domains	Mean variation of the pairwise log-ratios							
	Self-care /Domestic	**Physical Activity**	**Social**	**Education**	**Recreational Screen Use**	**Quiet Time**	**Sleep**	**Passive Transport**
Boys (n=276)								
Self-care/Domestic		1.178	6.257	0.286	0.905	8.794	0.247	0.843
Physical Activity	0.912		7.400	1.057	1.632	9.337	0.833	1.513
Social	0.101	0.652		5.581	6.237	12.944	5.446	5.709
Education	0.433	0.711	0.221		0.535	8.526	0.052	0.0614
Recreational Screen Use	3.704	3.639	3.259	2.790		9.345	0.555	1.293
Quiet Time	7.881	7.977	7.151	6.964	10.738		8.666	9.505
Sleep	0.306	0.462	0.151	0.063	2.813	7.277		0.683
Passive Transport	1.205	1.764	0.807	1.039	4.236	7.964	1.122	
Girls (n=337)								
Self-care/Domestic		1.700	6.068	0.225	0.986	8.888	0.186	0.870
Physical Activity	1.004		6.540	1.535	2.673	10.676	1.236	2.027
Social	10.818	10.581		5.887	6.940	13.970	5.493	6.818
Education	0.274	0.799	10.503		0.774	8.702	0.062	0.843
Recreational Screen Use	1.099	1.518	11.443	0.743		10.008	0.846	1.597
Quiet Time	5.980	6.561	16.866	5.769	6.788		8.985	9.112
Sleep	0.192	0.564	10.123	0.054	0.748	5.799		0.861
Passive Transport	1.591	2.217	11.865	1.449	2.294	7.751	1.515	

Note. The lower triangle of the pairwise log-ratios section refers to the mean variation of the log-ratios for activity domains at T1 (e.g., the mean variation for ln(Physical Activity/Self-care Domestic) among the boys is 0.912), whereas the upper triangle refers to the mean variation of the log-ratios at T2. The mean variation of the inverted log-ratios is not shown in the table as the variation matrix of log-ratios is symmetrical (e.g., ln(Self-care Domestic/Physical Activity) among the boys is also 0.912 at T1).

b) Non-school day sample (n=296)

Domains	Mean variation of the pairwise log-ratios							
	Self-care /Domestic	**Physical Activity**	**Social**	**Education**	**Recreational Screen Use**	**Quiet Time**	**Sleep**	**Passive Transport**
Boys (n=150)								
Self-care/Domestic		1.660	10.526	0.458	1.161	11.317	0.605	1.012
Physical Activity	2.242		11.474	1.008	1.401	12.639	0.755	1.602
Social	14.514	15.198		9.319	10.704	16.967	9.319	10.458
Education	0.669	1.204	13.565		0.378	10.363	0.074	0.596
Recreational Screen Use	1.553	1.693	14.599	0.379		10.900	0.388	1.404
Quiet Time	9.195	12.102	22.123	8.674	9.148		10.961	11.952
Sleep	0.804	0.939	13.503	0.055	0.414	9.162		0.910
Passive Transport	1.416	2.409	14.140	0.941	1.733	11.167	1.270	
Girls (n=146)								
Self-care/Domestic		4.253	7.975	0.338	1.401	10.402	0.377	3.341
Physical Activity	5.200		13.847	4.072	5.944	14.150	3.642	7.624
Social	13.066	15.686		7.324	8.015	16.835	7.186	11.888
Education	0.344	4.445	12.439		0.742	9.791	0.077	3.280
Recreational Screen Use	0.951	5.665	14.229	0.431		11.298	0.833	4.828
Quiet Time	8.150	12.281	19.371	7.713	8.782		10.546	13.795
Sleep	0.372	4.171	12.532	0.064	0.533	8.050		3.768
Passive Transport	1.698	4.724	11.658	1.097	2.007	9.880	1.467	

Note. The lower triangle of the pairwise log-ratios section refers to the mean variation of the log-ratios for activity domains at T1 (e.g., the mean variation for ln(Physical Activity/Self-care Domestic) among the boys is 2.242), whereas the upper triangle refers to the mean variation of the log-ratios at T2. The mean variation of the inverted log-ratios is not shown in the table as the variation matrix of log-ratios is symmetrical (e.g., ln(Self-care Domestic/Physical Activity) among the boys is also 2.242 at T1).

Appendix 6.5 Compositional descriptive statistics of the 24-hour domain-specific movement behaviour composition at primary (T1) and secondary school (T2) time points for the boys (n=426)

Domains	Mean variation of the pairwise log-ratios								Compositional means/day			
	Self-care /Domestic	Physical Activity	Social	Education	Recreational Screen Use	Quiet Time	Sleep	Passive Transport	T1		T2	
									Min	%	Min	%
Self-care /Domestic		3.554	7.385	0.349	1.140	10.127	0.294	1.243	145	10.1	156	10.8
Physical Activity	1.204		10.248	3.598	4.692	12.878	3.128	4.711	142	9.9	97	6.7
Social	10.966	12.666		6.514	7.335	15.525	6.277	7.086	2	0.1	11	0.8
Education	0.458	1.060	11.528		0.791	9.925	0.065	1.003	90	6.2	79	5.5
Recreational Screen Use	1.301	1.893	11.957	0.752		11.179	0.808	1.719	160	11.1	240	16.7
Quiet Time	7.499	8.156	16.955	6.985	8.332		10.067	11.239	20	1.4	11	0.8
Sleep	0.315	0.755	11.042	0.079	0.733	7.162		1.077	830	57.6	787	54.6
Passive Transport	2.240	2.826	14.112	2.112	2.925	9.487	2.142		52	3.6	59	4.1

Note. The lower triangle of the pairwise log-ratios section refers to the mean variation of the log-ratios for activity domains at T1 (e.g., the mean variation for *ln*(Physical Activity/Self-care Domestic) is 1.204), whereas the upper triangle refers to the mean variation of the log-ratios at T2. The mean variation of the inverted log-ratios is not shown in the table as the variation matrix of log-ratios is symmetrical (e.g., *ln*(Self-care Domestic/Physical Activity) among the boys is also 1.204 at T1). The compositional means of time spent in each domain (linearly adjusted to 1440 min; reported as min/day and percentage of a 24-hour day) at T1 and T2 are presented in the final two columns.

Appendix 7.1 Descriptive characteristics (Time 1) of the participants included and excluded from longitudinal analysis

Characteristics	Included sample (n=88)	Excluded sample (n=39)	p-value[a]
Age (years)	11.8 (0.4)	11.5 (0.6)	0.015
Sex, % girls	59.1	53.8	0.581
Socio-economic status (SEIFA IRSD)	1003 (44)	950 (79)	<0.0001
BAZ	0.41 (1.12)	0.50 (1.18)	0.665
Pubertal progression score	2.03 (0.55)	1.98 (0.55)	0.575
Psychosocial health			
Internalising difficulties	5.4 (3.4)	5.7 (3.5)	0.650
Externalising difficulties	6.7 (3.2)	6.3 (3.3)	0.482
Total difficulties	12.2 (5.7)	12.0 (6.1)	0.897
Prosocial behaviour	7.9 (1.9)	7.5 (1.7)	0.207
Psychological distress	21.2 (6.7)	22.2 (7.0)	0.447

Data presented as mean (standard deviation) unless indicated.

[a] Differences between samples were tested using independent t-tests.

SEIFA=Socio-economic Indicators for Areas; IRSD=Index of Relative Social Disadvantage; BAZ=body mass index z-score.

Appendix 7.2 Pairwise log-ratio variation matrix for sleep, sedentary time, LPA and MVPA at baseline (T1)

	Cross-sectional sample (n=127)				Longitudinal sample (n=88)			
	Sleep	**SED**	**LPA**	**MVPA**	**Sleep**	**SED**	**LPA**	**MVPA**
Sleep	0	0.010	0.014	0.117	0	0.029	0.038	0.149
SED	0.010	0	0.011	0.109	0.029	0	0.062	0.224
LPA	0.014	0.011	0	0.129	0.038	0.062	0	0.126
MVPA	0.117	0.109	0.129	0	0.149	0.224	0.126	0

Note. A value closer to zero indicates higher co-dependency between the two behaviours. SED=sedentary time; LPA=light-intensity physical activity; MVPA=moderate- to vigorous-intensity physical activity.