Physical education pedagogies and physical activity in primary school children

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Abbreviations

%Ag	Percentage of agreement
afPE	Association for physical education
AUC	Area under the receiver operating characteristic curve
BMI	Body mass index
CG	Control group
CI	Confidence interval
ciAUC	Confidence interval of the area under the receiver operating characteristic curve
CK	Cohen's Kappa
cm	Centimetres
CON	Control
CONSORT	Consolidated standards of reporting trials
CVD	Cardiovascular disease
ECG	Electrocardiography
ENMO	Euclidean norm minus one
Hz	Hertz
ICC	Intraclass correlation coefficient
IMD	Index of multiple deprivation
INT	Intervention
IOTF	International obesity task force
Kg	Kilograms
LJMU	Liverpool John Moores university
NLP	Nonlinear pedagogy group
LP	Linear pedagogy group
LPA	Light physical activity
m	Meters
M30	Minimum acceleration within the most active half an hour of the day
M60	Minimum acceleration within the most active hour of the day
MAPE	Mean absolute percent error
METs	Metabolic equivalents
mg	Milligravity
min	Minutes
min:s	Minutes and seconds
MPA	Moderate physical activity
MVPA	Moderate to vigorous physical activity
MVPA%	Percentage of moderate to vigorous physical activity
NA	Missing data
OA	Osteoarthrosis
OR	Odds ratio
PA	Physical activity
PACES	Partnerships for Active Children in Elementary Schools
PE	Physical education

QPE	Quality physical education
ROC	Receiver operating characteristic
s	Seconds
SAMPLE-PE	Skill acquisition methods fostering physical literacy in early-physical education
SB	Sedentary behaviour
SD	Standard deviation
SE	Standard error
SEN	Special educational needs
SOFIT	System for observing fitness instruction time
SOFIT+	Modified system for observing fitness instruction time to measure teacher practices related to physical activity promotion in physical education
STEP	Space task equipment people
T0	Baseline data collection
T1	Post-intervention data collection
T2	Follow-up data collection
VPA	Vigorous physical activity
y	Year
β	Beta coefficient
σ^2	Intercept variance
τ_{00}	Random factor variance

Glossary

Accelerometers: consist in devices presenting either piezoelectric or capacitive sensors that transform mechanical forces into an electrical signal to calculate accelerations (Troiano et al., 2014).

Ecological validity: concerns the appropriate generalization of experimental findings to the real world outside the laboratory (Kihlstrom, 2021).

Euclidean Norm Minus One (ENMO): consists in a metric used to process raw acceleration data collected using accelerometers. ENMO concerns the vector computed by calculating the Euclidean Norm of the orthogonal raw accelerations measured on the x, y, and z axis adjusted for gravity via subtracting a fixed offset of one gravitational unit where negative values are rounded up to zero (Bakrania et al., 2016).

Habitual physical activity: in this thesis habitual physical activity was defined as the usual free living physical activity behaviors of an individual comprising any type of physical activity (e.g. recreational, sport related, incidental, exercise related).

Linear pedagogy: consists in a pedagogy based on the Information Processing learning theory about movement learning (Schmidt, 1975) and it is characterised by a teacher-centred approach to movement education, where the teacher is the main source of instructional content and leads the performers through direct instruction and a series of pre-determined learning activities (Gallahue et al., 2012; Metzler, 2017).

Moderate to vigorous physical activity: defined as physical activity where the individual's energy consumption is equal or higher than 3 metabolic equivalents (Saint-Maurice et al., 2016). Alternatively, moderate activities refer to activities that take moderate physical effort and make people breathe somewhat harder than normal while vigorous physical activities refer to activities that take hard physical effort and make people breathe much harder than normal (Hagströmer et al., 2006; IPAQ, 2011; Tremblay, 2012; Cleland et al., 2014; WHO, 2021).

Movement competence: denotes an individual's degree of proficient performance in a broad range of motor skills as well as the underlying mechanisms including quality of movement, motor coordination and motor control (Utesch and Bardid, 2019).

Nonlinear pedagogy: consists in a pedagogy based on Ecological Dynamics theoretical and philosophical foundations about movement learning (Araújo et al., 2006; Warren, 2006) and it concerns a learner-centred approach to movement education where children are provided with high levels of autonomy and are invited to explore different movement solutions while teachers create functional variability to foster their movement exploration (Chow and Atencio, 2014).

Pedagogical model: identifies learning outcomes of importance and provides theoretical and practical indications about how these learning outcomes could be best achieved through teaching practices and curriculum alignment (Armour, 2011).

Pedagogy: consists of interdependent elements comprising the curriculum, learning and teaching (Armour, 2011).

Physical activity: defined as any bodily movement produced by skeletal muscles that requires energy expenditure (Caspersen C, Powell K, 1985).

Physical literacy: defined as the motivation, confidence, physical competence, knowledge and understanding to value and take responsibility for engagement in physical activities for life (International Physical Literacy Association, 2017).

Reliability: can be defined as the consistency of measurements, or of an individual's performance, on a test; or the absence of measurement error (Atkinson and Nevill, 1998)

Validation: concerns the process of assessing the quality of a measurement method and includes the evaluation of validity and reliability (Impellizzeri and Marcora, 2009).

Validity: concerns the degree to which an assessment method measures what it purports to measure (Lohr, 2002).

Abstract

Many children do not engage in adequate levels of moderate to vigorous physical activity (MVPA) to benefit their health and development. Physical education (PE) is a key opportunity for children to learn movement skills that could foster their engagement in physical activity (PA). The development of movement competence is a core aim of early primary PE as foundational movement skills help to foster lifelong PA behaviours. There is a lack of evidence about how PE pedagogical approaches targeting movement skill outcomes might affect PA in children. Therefore, this PhD thesis aimed to examine how different PE pedagogies (Linear and Nonlinear pedagogies), underpinned by movement learning theories, influence 5-6-year-old children's PA levels during PE and their overall habitual PA.

Study 1 and **Study 2** within this PhD thesis validated assessment methods that were needed to assess PA and teaching practices associated with MVPA. **Study 3** and **Study 4** investigated how PE interventions guided by Linear and Nonlinear pedagogies affect children's MVPA and teaching practices during PE, as well as habitual PA in primary school children. The data used in **Study 2**, **Study 3** and **Study 4** were collected within the SAMPLE-PE project clustered randomised controlled trial where 360 children (age: 5.9 ± 0.3 years, 55% girls) from 12 primary schools were randomly allocated to a 15-week Linear Pedagogy (LP: n = 3) or Nonlinear Pedagogy (NP: n = 3) PE interventions delivered by trained coaches, or to a control group (n = 6), where schools followed usual practice. **Study 1** involved a sample of participants from a primary school that was not included in the SAMPLE-PE project.

Study 1 validated sedentary behaviour (SB), MVPA and vigorous PA (VPA) raw accelerometer cut-points in 5–7-year-old children as valid and reliable cut-points for ActiGraph GT9X devices were not published in the literature. Forty-nine participants (age: 6.5 ± 0.8 years, 55% girls) wore an ActiGraph GT9X accelerometer on both wrists and the right hip during a standardised calibration protocol and recess. Cut-points were generated using ROC analysis with direct observation as the criterion. Cut-points were optimised using confidence intervals

equivalency analysis and then cross-validated in a cross-validation group. All monitor placements demonstrated adequate levels of accuracy for SB and PA assessment.

Study 2 included a subsample of the SAMPLE-PE project participants represented by 162 children (age: 6.0 ± 0.3 years, 53% girls) from 9 primary schools and the study aimed to validate the modified System for Observing Fitness Instruction Time (SOFIT+) to measure teacher practices related to PA promotion in PE amongst 5-6-year-old-children. Video-recordings of 45 PE lessons from nine teachers/coaches were coded using a modified version of the SOFIT+ while accelerometers were used to measure children's MVPA. It was found that SOFIT+ was a valid and reliable assessment of teaching practices related to MVPA promotion in PE amongst 5-6-year-old-children.

Using the same participants and dataset as **Study 2**, **Study 3** aimed to assess and compare children's PA and teaching practices related to PA promotion during PE lessons following Linear and Nonlinear pedagogical approaches. Linear pedagogy and Nonlinear pedagogy interventions were not associated with children engaging in higher MVPA during PE compared to participants in the control group and compared to each other. Despite this, Linear and Nonlinear interventions generally presented higher percentages of PA promoting teaching practices and lower MVPA reducing teaching practices compared to the control group. In particular, Linear and Nonlinear pedagogy involved increased *Motor Content* time (MVPA promoting practice) during PE compared to the control group. Additionally, the teaching practices observed in Linear and Nonlinear Interventions were in line with the respective pedagogical principles guiding PE delivery.

Study 4 included all the children participating in the sample PE project represented by 360 children (age: 5.9 ± 0.3 years, 55% girls) from 12 primary schools. **Study 4** aimed to assess how PE interventions guided by Linear pedagogy and Nonlinear pedagogy intervention affected children's habitual PA over the whole week and different segments of the week compared to the control group. ActiGraph GT9X accelerometers were used to assess PA metrics (MVPA, mean raw acceleration and lowest acceleration over the most active hour and half hour) over the whole week and week segments at baseline, immediately post-intervention and in a follow-up measurement 6 months after the end of the intervention. Intention to treat analysis employing multilevel modelling was used to assess intervention effects. Linear pedagogy and Nonlinear pedagogy interventions did not significantly affect children's PA levels compared to the control group. It was concluded that PE interventions based on Linear pedagogy and Nonlinear pedagogy alone might not be effective in improving habitual PA in children.

Based on the finding from this thesis 1) the accelerometers cut-points used in this thesis could be used by other researchers to assess PA in 5-7 years old children, 2) the methods used to validate accelerometer cut-points in this thesis could inform future calibration studies, 3) SOFIT+ could be used by both researchers and practitioners to assess teaching practices to achieve different aims (e.g. process evaluation of interventions, improving own teaching practices), 4) future Linear and Nonlinear interventions aiming at improving MVPA in PE should specifically target teaching practices aiming at increasing MVPA in PE (e.g. decreasing instruction time, improving verbal PA promotion), and 5) future PE interventions should be accompanied by other intervention components (e.g. increasing PA opportunities during school time, involving parents in PA promotion strategies) to successfully improve habitual PA levels in children.

Declaration
I declare that the work contained within this thesis is my own.

Outputs from this PhD work

Publications resulting from this PhD thesis

Crotti, M., Foweather, L., Rudd, J. R., Hurter, L., Schwarz, S., & Boddy, L. M. (2020). Development of raw acceleration cut-points for wrist and hip accelerometers to assess sedentary behaviour and physical activity in 5–7-year-old children. *Journal of Sports Sciences, 38*(9), 1036–1045. https://doi.org/10.1080/02640414.2020.1740469

Crotti, M., Rudd, J. R., Roberts, S., Boddy, L. M., Fitton Davies, K., O'Callaghan, L., Utesch, T., & Foweather, L. (2021). Effect of Linear and Nonlinear Pedagogy Physical Education Interventions on Children's Physical Activity: A Cluster Randomized Controlled Trial (SAMPLE-PE). *Children, 8*(1), 49. https://doi.org/10.3390/children8010049

Crotti, M., Rudd, J., Weaver, G., Roberts, S., O'Callaghan, L., Fitton Davies, K., & Foweather, L. (2021). Validation of Modified SOFIT+: Relating Physical Activity Promoting Practices in Physical Education to Moderate-to-vigorous Physical Activity in 5–6 Year Old Children. *Measurement in Physical Education and Exercise Science*. https://doi.org/10.1080/1091367X.2021.1901714

Oral presentations

- 10th May 2019 – **Crotti, M**, Rudd R, J, Roberts, Fitton-Davies, K, O'Callaghan, L, Foweather, L. "The role of pedagogies underpinning motor competence development in promoting physical activity in children during physical education lessons", Power of Sport conference in Liverpool (UK) (LJMU conference).

- 14th September 2019 – **Crotti, M**, Rudd R, J, Roberts, S, Utesch, T, Bardid, F, Cronin, C, Button, C, Lubans, D, Pesce, C, Fitton-Davies, K, O'Callaghan, L, Foweather, L. "Efficacy of SAMPLE-PE curriculum on physical activity within and beyond the school day". Symposium at "Healthy and active children Meeting" conference in Verona (Italy).
- 27th September 2019 – **Crotti, M**, Rudd R, J, Roberts, Fitton-Davies, K, O'Callaghan, L, Foweather, L. "The role of physical education pedagogies in promoting physical activity in children". Integrated Public Health-Aligned Physical Education conference in Columbia (South Carolina, USA).
- 8th January 2020 – **Crotti, M**, Rudd R, J, Roberts, Fitton-Davies, K, O'Callaghan, L, Foweather, L. "Effect of Linear and Non-Linear Pedagogy on Habitual Physical Activity (SAMPLE-PE)". 3rd Meeting of the UK and Ireland Children's Motor Competence Network conference in Liverpool (UK).
- 25th March 2020 & video recorded presentation on the 17th of June 2020 – "Effect of different pedagogical approaches in physical education on physical activity in primary school children". 3 minutes thesis competition at Liverpool John Moores University.

Poster presentations

- 1st May 2018 – **Crotti, M.**, Foweather, L., Rudd, J. R., Hurter, L., Schwarz, S., & Boddy, L. M. "Calibration of ActiGraph wrist-worn accelerometers raw acceleration thresholds for the assessment of physical activity and sedentary behaviour in 5-8 years old children". Institute of Health Research conference in Liverpool (UK) (LJMU conference).
- 20th June 2019 – **Crotti, M.**, Foweather, L., Rudd, J. R., Hurter, L., Schwarz, S., & Boddy, L. M. "Calibration of ActiGraph wrist-worn accelerometers raw acceleration

thresholds for the assessment of physical activity and sedentary behaviour in 5-8 years old children". Faculty of Education, Health and Community's Annual Research Day in Liverpool (UK) (LJMU conference).

- 25th June 2019 – **Crotti, M.**, Foweather, L., Rudd, J. R., Hurter, L., Schwarz, S., & Boddy, L. M. "Raw acceleration cut-points for the assessment of sedentary behaviour and physical activity in 5-7 year old children". International ICAMPAM conference in Maastricht (Netherlands).

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Chapter 1: Introduction

Context of this thesis

Physical activity in children

Promoting physical activity (PA) in children can be highly beneficial for their development as increased PA in children is associated with several positive outcomes for their health including improved quality of life (Marker et al., 2018), self-perception (Lubans et al., 2016), cardiovascular fitness (Tarp et al., 2016), metabolic function (Whooten et al., 2019) and cognitive development (Donnelly et al., 2016). Furthermore, children who are physically active are also more likely to become healthy and active adults (Telama et al., 2014). Yet, a large amount of children across the globe do not engage in the recommended guidelines of 60 minutes of moderate-to-vigorous physical activity (MVPA) per day for healthy growth and development (Janssen and LeBlanc, 2010; Griffiths et al., 2013; Roman-Viñas et al., 2016; Manyanga et al., 2019; Tanaka et al., 2020), with PA declining from early childhood (5-6 years old) towards adolescence. Furthermore, children from areas of high deprivation participate in even lower levels of PA than those from more affluent areas (Cooper et al., 2015; Love et al., 2019a). In view of this, a global call of action was raised to increase PA in children and decelerate or stop the PA decline from early childhood to adolescence (Ding et al., 2020).

The role of physical education in physical activity promotion

Physical education (PE) is a key occasion for many children to engage in structured PA in primary school (UNESCO, 2014). Furthermore, research showed that children engage in higher levels of MVPA during school days including PE than during school days not including PE (Yli-Piipari et al., 2016) suggesting that maximising MVPA in PE could facilitate children achieving the recommended PA guidelines. Therefore, public health arguments have been made suggesting that PE should focus on promoting PA and health along with other important outcomes such as the development of movement, cognitive, social and emotional skills (Meyer et al., 2012; Sallis et al., 2012; Kirk and Haerens, 2014). In line with this health related rationale, current PE curriculum guidelines from many national and international organizations state that children should be provided with a wide variety of meaningful and developmentally appropriate PA experiences and acquire skills to take part in PA throughout their life (Australian Curriculum Assessment and Reporting Authority, 2013; UK Department of Education, 2013; SHAPE America, 2015; UNESCO, 2015; afPE, 2020). Additionally, it was suggested that children should engage in MVPA over at least 50% of PE lessons time (Pate et al., 2006; AAHPERD, 2013; afPE, 2020). Despite these ambitions, recent studies show that students only spend between 9.5-42.4% of PE time in MVPA (Wood and Hall, 2015; Costa et al., 2016; Weaver et al., 2017; Tanaka et al., 2018). Furthermore, due to methodological limitations, weak evidence supports an effect of PE on habitual PA (Donnelly et al., 1996; Sallis et al., 1997; Manios et al., 1998; Caballero et al., 2003; Verstraete et al., 2007b; Chatzisarantis and Hagger, 2009; Sacchetti et al., 2013; Telford et al., 2016; Invernizzi et al., 2019; Kokkonen et al., 2019). Therefore, future research should investigate methods to maximise MVPA during PE while maintaining its educational components and clarify the effect of quality PE on children's habitual PA (Dudley et al., 2020).

Movement competence development for physical activity promotion in physical education

Movement competence is a central objective of PE (Australian Curriculum Assessment and Reporting Authority, 2013; UK Department of Education, 2013; SHAPE America, 2015; UNESCO, 2015; afPE, 2020), and is defined as an individual's degree of proficiently performing a broad range of movement skills (Utesch and Bardid, 2019). Movement competence does not develop by maturation alone (Gallahue et al., 2012). Children need to participate in PA to develop movement competence or learn new movement skills and evidence suggests this process can be assisted and enhanced through well designed PE curricula and PE delivery (Gallahue et al., 2012). Stodden et al. (2008) designed a conceptual model (Figure 1) to explain how movement competence and PA could mutually influence each other during childhood (Stodden et al., 2008).

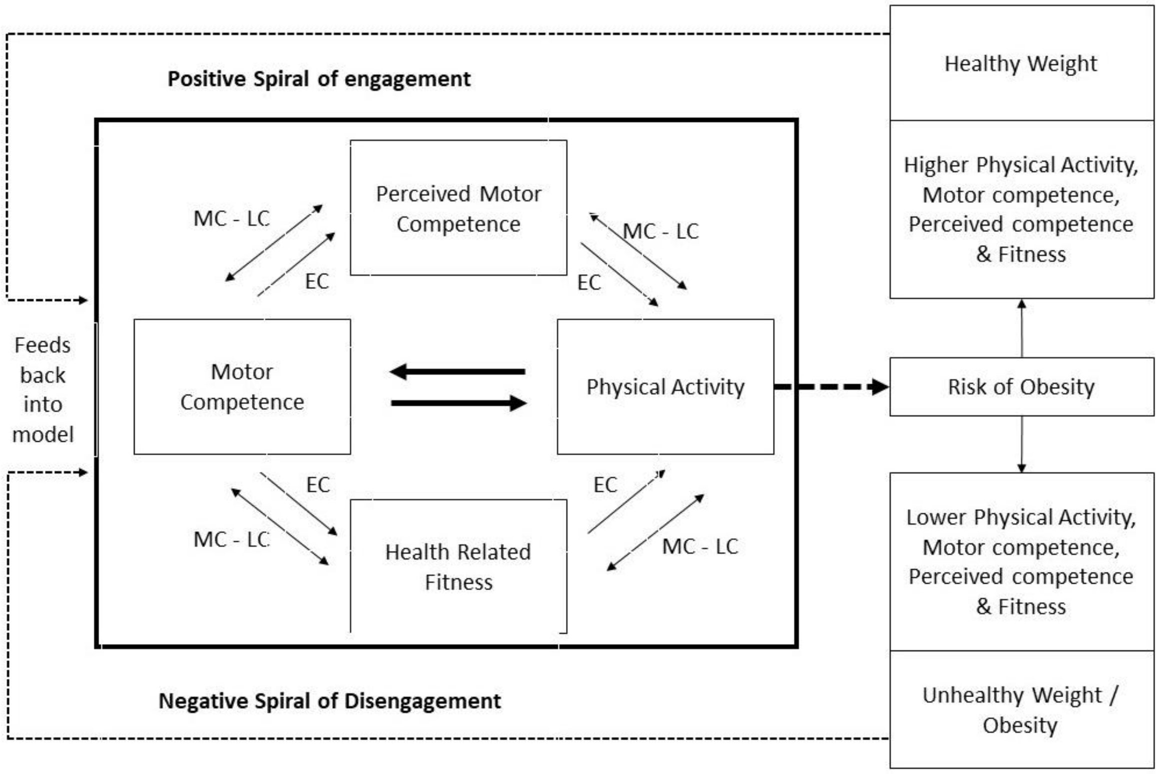

Figure 1. Conceptual model about developmental mechanisms influencing physical activity trajectories of children by Stodden et al (2008)

EC: early childhood; MC: middle childhood; LC: Late Childhood.

The model by Stodden et al. (2008) suggests that PA can foster movement development and in turn movement development can drive PA engagement in children while the relationship between motor competence and PA is mediated by children's perceived motor competence and health related fitness (Stodden et al., 2008). Furthermore, the model suggests that increased PA is associated with decreased risk for children to become obese while being obese would lead to a negative spiral of PA disengagement and low motor competence (Stodden et al., 2008). In line with the model by Stodden et al. (2008), strong and positive associations between PA and movement competence have been reported in the literature with more competent children being more physically active, suggesting that improvements in movement competence might foster PA engagement within and outside school in children (Robinson et al., 2015). To date few studies involving PE intervention reported positive effects on children's habitual PA (Boyle-Holmes et al., 2010; Bryant et al., 2016; Invernizzi et al., 2019) suggesting that a movement competence interventions might affect habitual PA in children. However, more evidence is needed to clarify the effectiveness of PE interventions focusing on movement competences in increasing PA during PE as well as habitual PA (Hollis et al., 2016; Engel et al., 2018; Errisuriz et al., 2018). Future research should therefore investigate how quality PE could promote PA as well as movement competence development.

Physical literacy in physical education

Physical literacy gained great popularity over the last two decades and has been recently recognised as a key aim of PE by many national institutions comprising institutions in UK (Green et al., 2018; National Assembly for Wales, 2019; UK Department of Education, 2019; Shearer et al., 2021). Physical literacy was defined by the International Physical Literacy association (IPLA) as "the motivation, confidence, physical competence, knowledge and understanding to value and take responsibility for engagement in physical activities for life" (International Physical Literacy Association, 2017). However, there is lack of a universally acknowledged definition of physical literacy (Shearer et al., 2018; Liu and Chen, 2020). Despite the inconsistencies between physical literacy definitions, movement competence development has been widely regarded as one of the key aspects of physical literacy (Edwards et al., 2017). Furthermore, most of physical literacy definitions suggest that physically literate individuals should be able to value and engage in PA throughout all their lifetime (Edwards et al., 2017; Shearer et al., 2018). Carney et al. (2019) designed a conceptual model (Figure 2) that could help explain how improving children's physical literacy could lead to an increase in their PA (Cairney et al., 2019). In particular, the left side of Carney et al. (2019) model (Figure 2) suggests that the physical literacy components (i.e. movement competence as well as PA related enjoyment, confidence, motivation, social interactions, knowledge and understanding) developed by an individual would interact with each other to determine PA engagement (Cairney et al., 2019). More specifically, improved physical literacy development would be associated with increased PA engagement. The left side of the conceptual model (Figure 2) instead suggests that PA behaviours together with other individual (e.g. age, sex, ethnicity) and environmental factors (e.g. weather, neighbourhood deprivation) should interact to determine individuals' physical, social and psychological health (Cairney et al., 2019). In particular, an increase in the amount of positive PA experiences would be associated with better health status and health related factors (e.g. increased cardiorespiratory fitness) (Cairney et al., 2019).

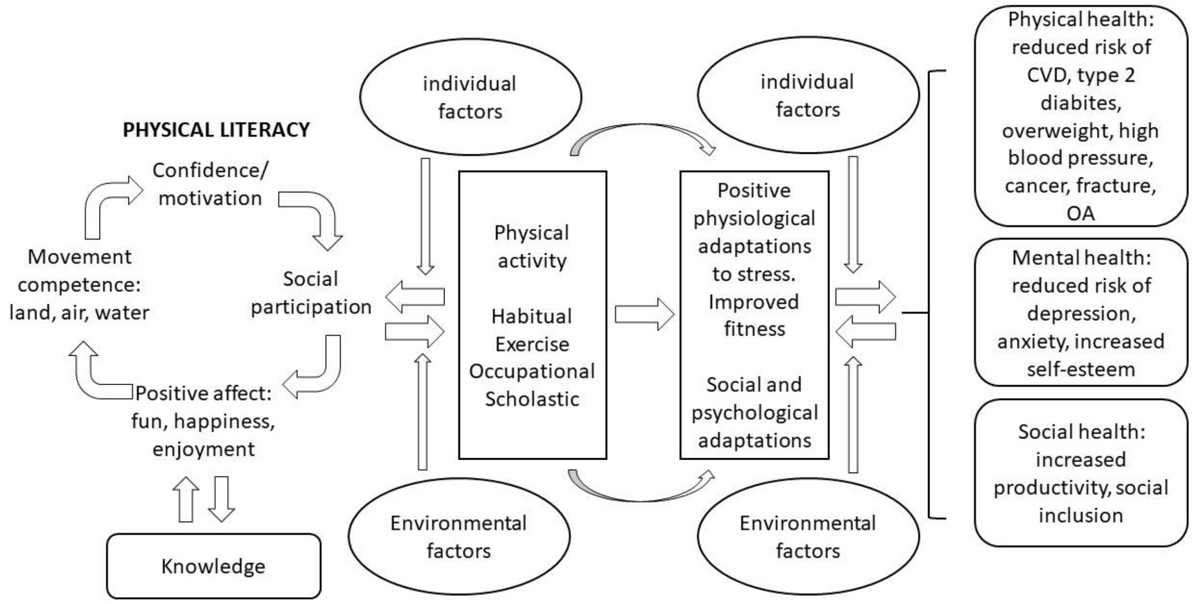

Figure 2. Conceptual model linking physical literacy, physical activity and health by Cairney et al. (2019)

CVD: cardiovascular disease; OA: osteoarthritis.

Therefore, developing physical literacy components during PE (e.g. movement competence), might positively influence other physical literacy components (e.g. willingness to participate in social PA events or enjoyment while participating in PA) that could lead to an increase in children's PA (Cairney et al., 2019). However, despite several interventions focused on promoting the achievement in physical literacy components, there is lack of research assessing the relation between physical literacy development and PA (Liu and Chen, 2020).

The role of pedagogies in promoting physical activity

PE programmes in schools often lack a theoretical basis guiding PE design and delivery (Kirk & Haerens, 2014). Pedagogical models provide PE teachers with the theoretical foundation and instructional options, necessary for the design and implementation of curriculum content so that children can achieve specific learning outcomes such as the improvement of movement skills (Kirk, 2013; Metzler, 2017). Linear and Nonlinear pedagogies are examples of pedagogical approaches designed to support children's movement development based on movement learning theories (Chow and Atencio, 2014; Metzler, 2017). For instance, Linear Pedagogy is based on the Information Processing theory about movement learning (Schmidt, 1975). From this perspective, providing students with specific sensory-motor input should enable them to produce specific movement outputs (Schmidt, 1975). Thus Linear pedagogy is reported as a teacher-centred instructional approach where students learn through repetition of movement tasks within a progression of increasing difficulty designed by the teacher (Gallahue et al., 2012; Metzler, 2017). Nonlinear pedagogy is based on the Ecological Dynamics theory of movement learning where learners are viewed as complex systems that interact with the environment in a unique way (Araújo et al., 2006; Warren, 2006; M. Newell, 2012). Nonlinear pedagogy is considered a learner-centred instructional approach where children are free to explore potential movement solutions within the environment while the teacher creates functional variability to foster their movement exploration. To date, no studies have evaluated the effect of these movement-focused PE pedagogies on children's PA engagement within and outside school (Chow and Atencio, 2014).

The role of teacher practices in physical education

PE teachers play a key role in transferring pedagogical theories into practice and the design of movement experiences in PE can have a significant impact on children's MVPA (Weaver et al., 2016; Fairclough et al., 2018). It is therefore important to assess teachers' behaviours during PE associated with PA promotion using valid and reliable methods (Weaver et al., 2016; Fairclough et al., 2018). However, the majority of previous PA research interventions in PE settings either did not report any aspect of teaching practices or reported *Lesson Context* information only (i.e. time spent in knowledge content, management of the class, game play, skill practice and fitness) while few studies reported other aspects of teaching practices that might affect children PA in PE (e.g. teacher promoting physical activity verbally, engaging in PA with the children, elimination games, proposing activities that involve waiting in a queue) (Hollis et al., 2016; McKenzie and Smith, 2017; Errisuriz et al., 2018). Therefore, future studies investigating interventions to affect PA in PE in children should also better evaluate teacher practices that might affect children PA levels.

Introduction to the thesis

The aim of this PhD thesis was to examine how different PE pedagogies (Linear and Nonlinear pedagogies) underpinned by movement learning theories might influence 5-6-years-old children's PA levels during PE and habitual PA. Linear and Nonlinear pedagogies are based on different theories and philosophical standpoints about movement learning but they both provide theoretical and practical applications for the development of movement competence in children.

Secondary aims of this PhD study concerned the validation of PA assessment in children and PA promoting teaching practice observation methods. More specifically, given that a valid and reliable measure of PA was needed to assess children's PA for this thesis and accelerometers present several advantages compared to other types of PA measurement (Migueles et al., 2017), this thesis involved a calibration study to validate children's PA assessment using accelerometers in 5-7 years old children. Furthermore, this thesis included a study concerning the validation of the modified System for Observing Fitness Instruction Time to Measure Teacher Practices Related to Physical Activity Promotion (SOFIT+). This study was included as previous observation tools did not capture important aspects of teaching practices that are typical of teacher-centred approaches such as Nonlinear pedagogy and teaching practices that are associated with children's MVPA in PE (Weaver et al., 2016). Furthermore, the validation of the SOFIT+ in children from UK was needed as no study assessed the cross-cultural validity of this observation tool in primary school children outside USA (Weaver et al., 2016).

This thesis comprises 4 studies that are reported in different chapters as shown within the thesis studies map (Table 1) and in the data collection map (Figure 3). Following this introductory chapter (**Chapter 1**), **Chapter 2** of this thesis provides an overview and critique of previous literature concerning: the association between PA and health in children, PA guidelines for children, methods to measure PA, children PA levels, the role of school and PE in promoting PA in children, previous PE interventions aiming to improve PA during PE or habitual PA, the role of teaching practices in determining PA in PE together with their assessment methods, and finally the role of movement competence in promoting PA and pedagogies in PE. **Chapter 3** concerns the first study of this thesis and involves the development of raw acceleration cut-points for wrist and hip GT9X ActiGraph accelerometers to assess sedentary behaviour and PA in 5–7-year-old children. **Chapter 4** includes the second study of this thesis and reports the validation of a modified version of the SOFIT+ for use in early primary PE. **Chapter 5** presents the third study of this thesis, which investigates children's PA and teacher practices during PE within Linear and Nonlinear pedagogy PE interventions groups compared to a control group that did not receive an intervention within the SAMPLE-PE project. The final study of this thesis (study 4) is reported in **Chapter 6** and concerns the effect Linear and Nonlinear PE interventions on children's habitual PA compared to a control group of children that did not receive an intervention within the SAMPLE-PE project. Lastly, **Chapter 7** provides a synthesis of the findings from the previously mentioned four studies reported in this thesis as well as conclusions, strengths, limitations, and future directions.

Table 1. Thesis studies map

Study	**Study content**
Study 1	Development of raw acceleration cut-points for wrist and hip accelerometers to assess sedentary behaviour and physical activity in 5–7-year-old children.
Study 2	Validation of modified SOFIT+: Relating physical activity promoting practices in physical education to moderate-to vigorous physical activity in 5-6 year old children.
Study 3	Teacher physical activity promoting practices and children's physical activity within physical education lessons underpinned by movement learning theories (SAMPLE-PE)
Study 4	Effect of Linear and Nonlinear pedagogy physical education interventions on children's physical activity: a cluster randomized controlled trial (SAMPLE-PE).

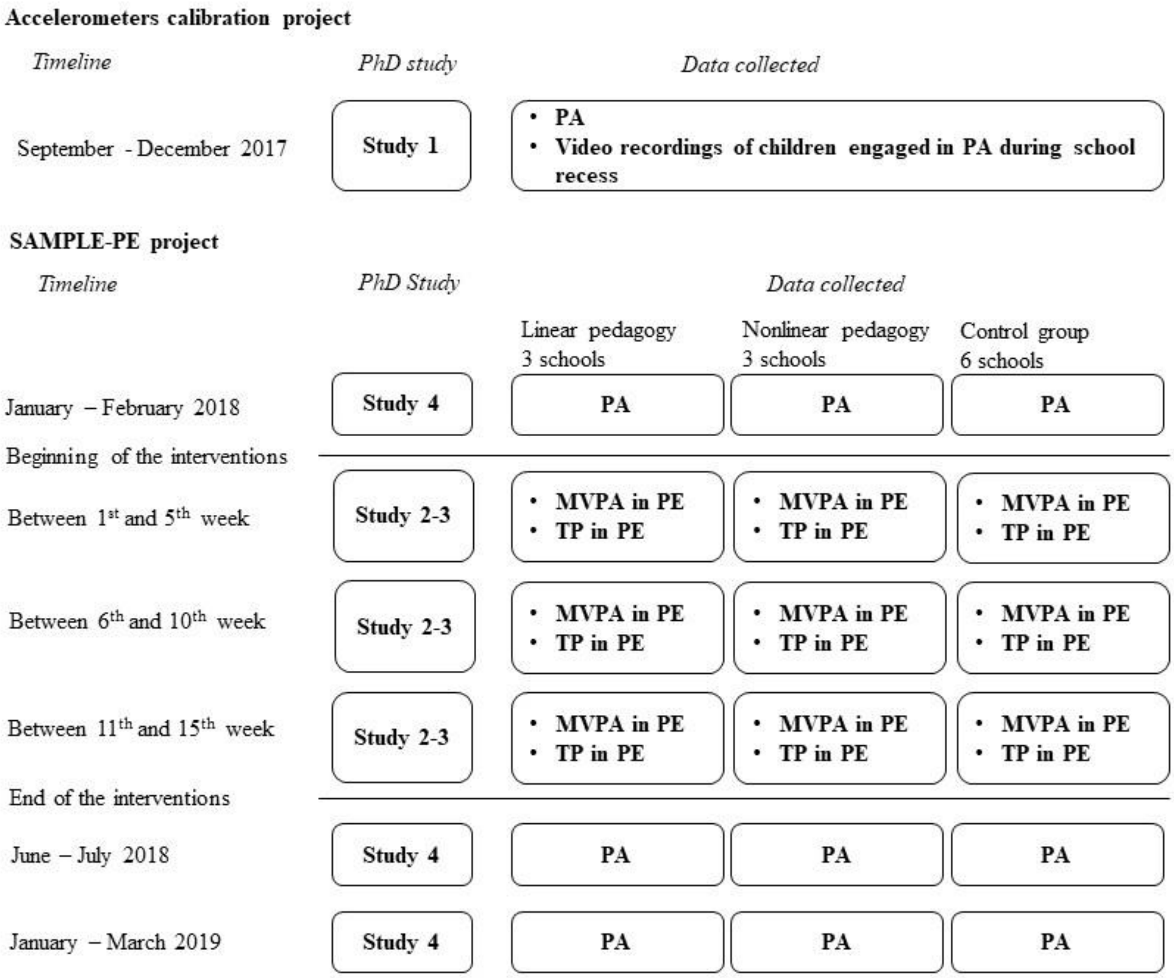

Figure 3. Schematic overview of PhD study data collection

PA: physical activity over a week; **MVPA:** moderate to vigorous physical activity; **PE:** physical education; **TP:** teaching practices.

Independent contribution to the thesis

This PhD thesis is part of the SAMPLE-PE cluster randomised controlled trial, which was funded by Liverpool John Moores University and is described in detail below. The project was led by Dr James Rudd and Dr Lawrence Foweather and included myself together with two other PhD students who evaluated psychological and cognitive outcomes, respectively, within the 5-6-year-old children participating in the trial. The trial involved a large collaborative team of researchers from within Liverpool John Moores University and other institutions (Rudd et al., 2020a). The core research team (i.e. Principal investigators and PhD students) met regularly to discuss and reach consensus about important decisions concerning the project. The following section reports my specific role and contribution to each of the studies reported in this thesis:

- Chapter 3 (study 1)

Study design; data collection; data analysis; writing the study; production of tables; production of figures.

- Chapter 4 (study 2)

Study design; data collection; data analysis; writing the study; production of tables.

- Chapter 5 (study 3)

Study design; data collection; data analysis; writing the study; production of tables; production of figures.

- Chapter 6 (study 4)

Study design; data collection; data analysis; writing the study; production of tables; production of figures.

Overview of the SAMPLE-PE project

The SAMPLE-PE cluster randomised controlled trial investigated the effect of PE Linear and Nonlinear pedagogy curricula on physical literacy development in 5-6-year-old children (Rudd et al., 2020a). The primary outcome was movement competence (comprising movement proficiency and movement creativity) with secondary outcomes comprising physical activity, enjoyment, motivation and cognition (Rudd et al., 2020a). The SAMPLE-PE project cluster randomised trial was approved by the University Research Ethics Committee (Reference 17/SPS/031), it was registered within ClinicalTrials.gov (identifier: NCT03551366) and it was described in detail in a published study protocol (Rudd et al., 2020a). A schematic diagram providing an overview of the SAMPLE-PE randomised controlled trial components and design can be found in Figure 4.

Briefly, primary schools from deprived areas in the North West of England were contacted and invited to take part in the SAMPLE-PE project. The Head-teachers of 12 primary schools provided informed consent to participate. Subsequently, Year 1 children (5-6-years-old) within the participating schools were invited to take part in the study and parental informed consent together with child assent to participate in the study were collected. The 12 schools were randomly allocated to a Nonlinear pedagogy intervention group (3 schools), a Linear pedagogy intervention group (3 schools), or a Control group (6 schools). Baseline data (T0) collection occurred in January-February 2018. At baseline, movement competence, perceived movement competence, motivation, executive functions self-regulation and habitual physical activity were assessed in children. The intervention started immediately after baseline assessments and consisted of two PE lessons per week for 15 weeks, delivered by trained coaches. Control group schools were asked to provide their usual PE practice for two lessons per week during the same period. Process evaluation assessments were performed once every 5 weeks within the Intervention groups and in a subsample of the control group (3 schools).

Process evaluation assessments comprised basic psychological need satisfaction, basic psychological need support, PA in PE, and teacher practices in PE. Post-intervention assessments (T1) were completed within 2 weeks after the intervention period between June and July 2018 and involved the same assessments that were done at baseline plus interviews with coaches, teachers and head-teachers. The follow-up assessments (T2) took place 6 months after post-intervention assessments between January and early March 2019 and involved the assessment of movement competence, perceived movement competence, executive functions self- regulation and habitual PA in children.

Apart from study 1, all the studies in this thesis included data collected within the SAMPLE-PE project (Figure 3). More specifically, study 1 was approved by the University Research Ethics Committee (Reference: 17/SLN/004) within an ethics application that was not related with the SAMPLE-PE project. Whereas, study 2 and study 3 involved data collected during the SAMPLE-PE project intervention period while study 4 involved outcomes collected before the intervention period (T0), after the intervention period (T1) and 6 months after the end of the intervention period (T2) within the SAMPLE-PE project (see Figures 3 and 4).

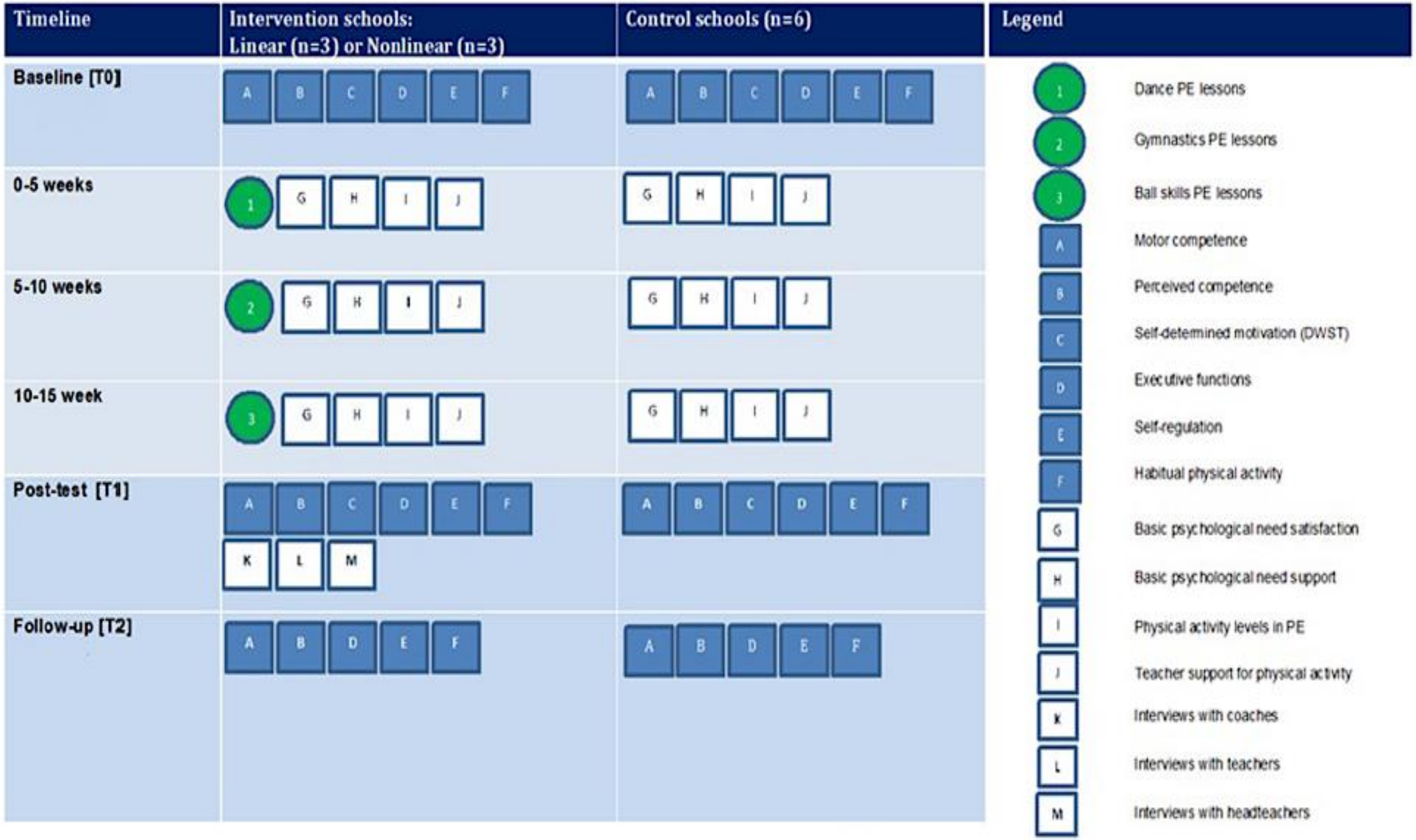

Figure 4. SAMPLE-PE project schematic overview

Chapter 2: Literature review

Physical activity: definition and classification

School-aged children who engage in high levels of PA experience better physical, social and mental health compared to their peers presenting low PA levels (Tan et al., 2014; Lubans et al., 2016; Poitras et al., 2016; Tarp et al., 2016; Marker et al., 2018; Whooten et al., 2019; Reisberg et al., 2020). However, high proportions of children do not engage in adequate levels of PA in many countries across the globe and PA progressively declines while SB increases from the age of school entry (i.e. 5-6 years) (Griffiths et al., 2013; Konstabel et al., 2014; Cooper et al., 2015; Roman-Viñas et al., 2016; Farooq et al., 2018; Manyanga et al., 2019; Tanaka et al., 2020). It is therefore critical to measure PA in primary school children, to monitor population trends and to design and evaluate the effectiveness of interventions that could increase PA in this population.

PA is defined as any bodily movement produced by skeletal muscles that requires energy expenditure (Caspersen C, Powell K, 1985). PA is classified into different intensities based on the energy expenditure of the body using Metabolic equivalents (METs), where one MET equals the resting energy expenditure. One MET is equivalent to 3.5 ml of oxygen per kg per minute in adults (Saint-Maurice et al., 2016). In children, resting energy expenditure levels are higher in terms of oxygen consumption (1.2 - 1.7 times the adult METs) and therefore it is suggested that METs in children should be based on child specific resting energy expenditure METs (Harrell et al., 2005; Saint-Maurice et al., 2016; Butte et al., 2018). The most widely accepted PA intensity thresholds based on METS for children are as follows: Sedentary Behaviors (SB) (≤1.5METs), Light PA (LPA) (≥1.5–<3METs), Moderate PA (MPA) (≥3–<6 METs), and Vigorous PA (VPA) (≥6 METs) (Saint-Maurice et al., 2016).

Other qualitative descriptions of PA intensity levels, often used in PA questionnaires, comprise:

- Sedentary is described as any waking behaviour while sitting and reclining or lying such as the use of electronic devices (e.g. television, computer, tablet, phone) while sitting, reclining or lying; reading/writing/drawing/painting while sitting; homework while sitting; sitting at school; sitting in a bus, car or train (Tremblay, 2012; Tremblay et al., 2017).
- Light PA is described as activity while standing or walking slowly that does not lead to breathing harder than normal (Weston et al., 1997; WHO, 2020, 2021).
- Moderate activities refer to activities that take moderate physical effort and make you breathe somewhat harder than normal (Weston et al., 1997; WHO, 2020, 2021).
- Vigorous physical activities refer to activities that take hard physical effort and make you breathe much harder than normal (Weston et al., 1997; WHO, 2020, 2021).

PA can also be classified into categories concerning PA function or domain (e.g. locomotion, work, leisure activities and exercise) (Butte et al., 2012; Hidding et al., 2018) or based on specific activity types (e.g. walking, doing jumping jacks, playing soccer, skying) (Butte et al., 2018; Hidding et al., 2018). PA type can be assessed using different methods such as self-report, direct observation or through sophisticated devices-based methods recognizing acceleration patterns (Aparicio-Ugarriza et al., 2015; Allahbakhshi et al., 2019). Furthermore, PA type can also be used as an indicator of PA intensity (Butte et al., 2018). For example, a compendium of youth physical activities was created reporting several PA types as well as the average energy expenditure levels associated with each activity type in children (Butte et al., 2018). However, the majority of studies assessing PA in children report duration or frequency of different PA intensities rather than PA type (Quitério, 2013; Hollis et al., 2016; Errisuriz et al., 2018; Love et al., 2019b).

Physical activity and health

Increased levels of MVPA in children are associated with a number of positive developmental outcomes such as improved cardiovascular fitness (Tarp et al., 2016), metabolic function (Whooten et al., 2019), strength (Poitras et al., 2016), bone health (Tan et al., 2014), body composition (Reisberg et al., 2020), self-perception (Lubans et al., 2016), cognition (Donnelly et al., 2016) and quality of life (Marker et al., 2018), together with decreased cardiovascular risk (Tarp et al., 2016). The advantage of MVPA in terms of health promotion and disease prevention is that the effects of PA are systemic, meaning that PA positively affects different systems in our body simultaneously including the cardiovascular, hormonal, sympathetic and parasympathetic neuronal, metabolic, muscular and skeletal systems (Kenney et al., 2020). In view of the above, it is important to make sure that children participate in adequate amount of PA to positively impact their health and well-being.

Physical activity guidelines

Based the health benefits associated with PA during childhood reported in the literature, national and international organizations have published and adopted different PA guidelines for children (Janssen and LeBlanc, 2010; Gelius et al., 2020).

In 2020, the World Health Organization (Chaput et al., 2020) published updated PA guidelines for children recommending that:

- Children and adolescents aged between 5-17 years should engage in at least an average of 60 minutes per day of MVPA, mostly aerobic, physical activity, across the week. (Strong recommendation, moderate certainty evidence).
- Incorporate vigorous-intensity aerobic activities, as well as those that strengthen muscle and bone at least 3 days a week. (Strong recommendation, moderate certainty evidence).

- Should limit the amount of time spent being sedentary, particularly the amount of recreational screen time. (Strong recommendation, low certainty evidence).

As concerns PA guidelines in the UK, recommendations for children and youth (aged between 5 and 18 years) were recently published in 2019 by the UK Chief Medical Officers' stating (Davies et al., 2019):

- Children and young people should engage in moderate-to-vigorous intensity physical activity for an average of at least 60 minutes per day across the week. This can include all forms of activity such as physical education, active travel, after-school activities, play and sports.
- Children and young people should engage in a variety of types and intensities of physical activity across the week to develop movement skills, muscular fitness, and bone strength.
- Children and young people should aim to minimise the amount of time spent being sedentary, and when physically possible should break up long periods of not moving with at least light physical activity.

The UK PA guidelines are mostly in line with the World Health Organization PA guidelines. However, it should be noted that the UK PA guidelines specifically mention the importance of engaging in PA in different forms comprising PE, active travel, after-school activities, play and sports (Davies et al., 2019; Chaput et al., 2020). Furthermore, UK guidelines recognised that developing movement skills is likely to be beneficial for PA engagement in children despite suggesting that more robust experimental evidence is needed to clarify this (Davies et al., 2019).

Physical activity assessment

Accurate measurements of PA in children are needed for several reasons such as evaluating the association between PA and health, calculating health risks, providing PA recommendations, assessing population inequalities in PA, identifying specific populations with low PA levels and evaluating the effects of PA interventions (Sallis et al., 2000; Loprinzi and Cardinal, 2011). To date, several tools and methods have been developed and validated to evaluate different dimensions of PA in children (Ainsworth et al., 2015; Aparicio-Ugarriza et al., 2015).

Doubly labelled water is considered the gold standard for the measurement of energy expenditure in free living conditions that provides an indication of overall PA (Schoeller et al., 1995; Ekelund et al., 2001; Ndahimana and Kim, 2017). This method consists of calculating energy expenditure from the difference in hydrogen and oxygen isotopes disappearance kinetics in bodily fluids (Schoeller et al., 1995). However, doubly labeled water does not provide information about intensity, duration, frequency and type of PA and the cost associated with this measurement are high (Ainsworth et al., 2015; Aparicio-Ugarriza et al., 2015).

Direct calorimetry is another method to assess energy expenditure and can be used in children (Kenny et al., 2017; Ndahimana and Kim, 2017). It consists of measuring the rate of heat loss produced by the individual within a calorimetry chamber to estimate energy expenditure (Kenny et al., 2017). Direct calorimetry is highly accurate, however, as with doubly labelled water, it cannot be used to assess intensity, duration, frequency, and type of PA. Furthermore, calorimetry cannot be used to assess habitual PA and it requires very expensive equipment (Ainsworth et al., 2015).

Indirect calorimetry can also be used to assess energy expenditure in children. This method allows the assessment of METs and therefore can classify PA according to intensity (e.g. SB, LPA, MPA, VPA) in children (Butte et al., 2018; Mtaweh et al., 2018). Current devices permit automated and continuous assessment of respiratory gasses and ventilation. Traditional indirect calorimetry devices cannot be used to assess habitual PA as they cannot be transported by individuals outside a laboratory setting. Wearable indirect calorimetry devices have been developed to assess free living PA (Tamura, 2019). However, indirect calorimetry devices can only be used for up to few hours and they are an invasive assessment method as devices weigh more than half kilogram and assessment involves wearing a mask covering the mouth and nose (Tamura, 2019), limiting their use in assessing habitual PA in children. Lastly, another disadvantage of indirect calorimetry devices is their high cost (Ainsworth et al., 2015).

Hearth rate monitors can also be used to assess energy expenditure and PA levels in children based on physiological variables (Loprinzi and Cardinal, 2011). Children’s heart rate can be measured using electrocardiography (ECG) or chest-strap telemetry (Ndahimana and Kim, 2017). Heart rate measurement presents several limitations comprising the lack of studies about validity in assessing children’s PA, the requirement of complex calibration methods due to individual differences in resting heart rate, and the use of invasive equipment (e.g. chest straps and heart rate Holter) (Eckard et al., 2019). Wrist-worn photoplethysmography devices could represent a less invasive method to assess heart rate for long period of time, however, there is lack of validation studies of these devices in children (Zhang et al., 2020).

Self-report PA measurement methods are the least expensive and most time efficient method to assess PA in children and include questionnaires, PA logs and diaries (Ndahimana and Kim, 2017). Self-report methods can capture information about PA intensity and frequency and also PA type in children (Loprinzi and Cardinal, 2011; Ainsworth et al., 2015). Questionnaires are the most widely used self-report methods, however, they involve risks of bias such as recall and social desirability bias and they lead to poor estimate of PA especially in young populations (Warren et al., 2010; Hidding et al., 2018). PA logs and diaries can reduce the recall bias however they can represent a high burden for participants and are not an appropriate measurement for young children who might not be able to recall and report their PA over the day. Furthermore, parents might not be able keep accurate PA diaries for children if they cannot observe them all day (Loprinzi and Cardinal, 2011; Ndahimana and Kim, 2017).

Direct observation (also defined systematic observation within the literature) is another commonly used method to assess behaviours (such as PA) in children (Loprinzi and Cardinal, 2011). Direct observation methods can provide valid and reliable measurements of PA duration, type, intensity and can be used to assess free living activity in different settings (Aparicio-Ugarriza et al., 2015; Cox et al., 2020). Direct observation methods typically involve one or more observation tactics to assess PA such as "event recording" (i.e. assessing the frequency count of a behaviour), "duration recording" (i.e. providing information about the length of time of a behaviour), "interval recording" (i.e. concerning the measurement of occurrence of behaviours during specific time intervals) and "momentary time sampling" (i.e. a recording method where the coding decision about a behaviour happens at the end of an observation interval) (McKenzie and Mars, 2015). An example of direct observation tool is the Children's Activity Rating Scale (CARS) that was designed to categorize the intensity of children's PA in five levels comprising: 1) stationary - no movement, 2) stationary - with movement, 3) translocation - slow/easy, 4) translocation - medium/moderate, and 5) translocation - very fast/strenuous (Puhl et al., 2013). Similarly, other observation tools such as the System for Observing Instruction Fitness Time (SOFIT) or the System for Observing Children's Activity and Relationships during Play (SOCARP) can be used to categorize children's PA behaviours in five PA types or levels comprising: 1) sitting, 2) lying, 3) standing, 4) walking and 5) vigorous PA (McKenzie et al., 1992; Ridgers et al., 2010). An advantage of direct observation tools such as SOFIT and SOCARP is that they can be used for the simultaneous assessment of information about PA as well as the physical environment and the social environment where PA takes place (e.g. lesson context, instructor behaviours, group size, activity type) (McKenzie and Mars, 2015). In particular, direct observation methods are widely used to observe teachers or sport coaches behaviors during PE or coaching sessions involving children (McKenzie and Mars, 2015; Cope et al., 2017). Further advantages of direct observation methods are the high ecological validity and low participant burden (McKenzie and Mars, 2015). However, analysis of observation data is time expensive, generally requires a period of observer training and inter- or intra- rater reliability assessment, and it is not a viable method to assess habitual PA over long periods due to time constraints and ethical issues (Aparicio-Ugarriza et al., 2015).

Pedometers are widely used devices involving motion sensors that count the number of steps made by an individual (Bassett et al., 2017). Pedometer devices generally present reduced cost compared to other wearable devices used to assess PA, they are not invasive and they can assess children's steps over a long period during everyday life (Loprinzi and Cardinal, 2011). A weakness of traditional pedometers is that wear compliance was generally based on participants' self-report and devices were not designed to store data about step frequency (Clemes and Biddle, 2013). Modern devices assessing step counts (generally including accelerometer sensors) were designed to store data about step frequency and therefore can be used to derive PA intensity, PA duration and wear time in children (Bassett et al., 2017). However, step count thresholds to derive time in MVPA from pedometers led to inaccurate estimate of MVPA in children (Beets et al., 2011; Howe et al., 2018).

Accelerometry is another widely used device-based method to assess PA and it presents many advantages in assessing habitual PA in children compared to other assessment methods (Trost et al., 2011; de Almeida Mendes et al., 2018; Leeger-Aschmann et al., 2019; Love et al., 2019b). These advantages include: not being an invasive assessment, the possibility to monitor individuals for a long period of time including during sleep, the possibility to calculate non-wear time, the possibility to assess different aspects of PA (e.g. PA duration, PA frequency, PA intensity, PA type, energy expenditure), an existing large literature reporting validity and reliability aspects of accelerometers, and lastly the fact that accelerometers are a feasible method to assess PA in large populations (Aparicio-Ugarriza et al., 2015; Migueles et al., 2017;

Montoye et al., 2018). Furthermore, despite being generally more expensive than pedometers, the cost of accelerometers is generally not prohibitive for research institutions (Aparicio-Ugarriza et al., 2015; Migueles et al., 2017; Montoye et al., 2018). A disadvantage of accelerometer assessment is that different accelerometer brands, wearing location and accelerometer PA thresholds were found to provide unequal PA estimates in children (van Hees et al., 2016; Montoye et al., 2018). Furthermore, depending on the wear location or accelerometer characteristics some activities such as cycling and swimming cannot be detected or assessed using these devices (Butte et al., 2012).

Multiple sensors systems were also developed combining different sensors (e.g. accelerometers, heart rate, galvanic skin response, skin temperature sensor) and were generally used to derive children energy expenditure (Calabró et al., 2009; De Bock et al., 2010; Lee et al., 2016). However, due to the complexity of data analysis required, limited calibration studies and high costs, multiple sensor systems are often not employed in research (Butte et al., 2012; Ainsworth et al., 2015).

Physical activity assessment using accelerometers

Accelerometers provide valid and reliable PA measurement in children and they are widely used in research because of the advantages reported in previous section (Trost et al., 2011; de Almeida Mendes et al., 2018; Leeger-Aschmann et al., 2019; Love et al., 2019b). Accelerometers generally present either piezoelectric or capacitive sensors that transform mechanical forces into an electrical signal to calculate accelerations (Troiano et al., 2014). Newer devices are designed to record accelerations up to 100 times per second (20-100Hz of frequency) for two weeks or more (Rowlands et al., 2018b). Acceleration data are stored within the devices and then downloaded after the recording time has ended. Accelerometers are fitted to the body using different methods (e.g. elastic belts, straps or medical tape) depending on the wear position selected and depending on the acceleration of the specific segment of the body (e.g. ankle, wrist, hip) measured (Migueles et al., 2017). During the initial stages of accelerometer PA research, hip-worn accelerometers were the most used devices (Troiano et al., 2014). A limitation of hip-worn monitors is that they obtained low wear compliance, particularly in studies where participants were asked to take them off when going to bed (Fairclough et al., 2016). Another limitation of hip-worn devices is that they do not capture the movement of upper body that accounts for a high proportion of energy expenditure particularly during object control activities (Butte et al., 2018). More recently, wrist-worn accelerometers have been used extensively in research. Wrist worn-accelerometers are more sensitive to upper body movement and they generally led to better compliance compared to waist worn devices (Fairclough et al., 2016). However, there is no conclusive evidence to establish whether hip or wrist accelerometer placement provides the most accurate assessment of PA in children and more research is warranted.

Traditionally, recordings from accelerometers were transformed into proprietary counts (Troiano et al., 2014). However, brand specific algorithms created to calculate PA count data made it difficult, if not impossible, to compare results collected from different devices (Chen and Bassett, 2005). Therefore, is was suggested that raw acceleration output should be preferred to count-based measurement to facilitate future harmonisation of PA methods (van Hees et al., 2016). In line with this, recent research evaluating raw accelerometer output in devices from different brands showed that these devices presented good agreement despite presenting small brand specific differences (Rowlands et al., 2018b). Between different raw acceleration metric, Euclidean Norm Minus One (ENMO) is emerging as the most widely used one. ENMO concerns the vector computed by calculating the Euclidean Norm of the orthogonal raw accelerations measured on the x, y, and z axis adjusted for gravity via subtracting a fixed offset of one gravitational unit where negative values are rounded up to zero

(Bakrania et al., 2016). An open access statistical package called GGIR has been developed to calculate the ENMO metric using raw acceleration output derived by different accelerometer brands (Bakrania et al., 2016; Migueles et al., 2019). Using ENMO metric could help facilitate the comparison between accelerometer outputs derived from different accelerometers brands and consequently it could help comparing PA measurements reported in different studies. Therefore, future accelerometer validation studies should use raw accelerometer metrics such as ENMO to facilitate harmonisation of PA assessment methods in the future.

Accelerometers can be used to assess different aspects of PA in children comprising PA type, PA intensity and can also be used to assess postures (van Loo et al., 2017; Allahbakhshi et al., 2019). However, studies using accelerometers to assess habitual PA in children generally report time spent in different PA intensities (comprising SB, LPA, MPA and VPA), and, in particular, time spent in MVPA (Konstabel et al., 2014; Brown et al., 2016; Harrison et al., 2017; Farooq et al., 2018). Several cut-points (or thresholds) have been developed to classify either count-based output or raw accelerations outputs into different PA intensities in children (Trost et al., 2011; Van Loo et al., 2017, 2018). Cut-points classify accelerometer output over a specific window of time called an epoch. The length of epochs generally varies from 1 to 60 seconds. In the first stages of accelerometers usage, epoch lengths were generally set at 60 seconds because of limited accelerometer memory storage (Trost et al., 2011; Migueles et al., 2017). Due to advances in technology, newer accelerometers can store more data and different epoch lengths have been used depending on the population studied. For example, the most recently developed cut-points to assess children generally involve 1 second epochs to account for the sporadic and intermittent changes in PA intensity typically observed in children (Bailey et al., 1995; Baquet et al., 2007; Van Loo et al., 2018). Another important feature of cut-points is that they are age specific as PA patterns and therefore cut-points validated in a specific age group (e.g. adolescents) should not be used in other age groups (e.g. children). Furthermore, accelerometers from different brands or different accelerometers models from the same brand present slight differences in accelerometer output (Rowlands et al., 2018b; Clevenger et al., 2020). Therefore, it is recommended to use cut-points that are specific for the brand an accelerometer model used as well and specific to the age group to assess. Among different accelerometer brands, ActiGraph is one of the most frequently used by researchers (Migueles et al., 2017). However, no study has established raw acceleration cut-points for ActiGraph devices to assess PA in 5-6 year old children.

A limitation associated with cut-points is that they are strongly dependent on the calibration protocol used to create them (Trost, 2007). For example, the selection of different activities within the protocol (e.g. running, bouncing a ball, writing) and the methods used to identify cut-points (e.g. Receiver Operating Characteristic (ROC) analysis or regression methods) could affect the final cut-points selection (Trost et al., 2011). Moreover, the characteristics of the population included in the calibration study (e.g. age range) might also potentially lead to differences in the PA levels measured and therefore in the cut-points selection (Trost, 2007). As a consequence, cut-points developed for the same age group might lead to discrepant PA results (Trost et al., 2011; Van Loo et al., 2017). Recently, cut-point free data driven acceleration metrics were proposed that provide different insights into a person's PA profile compared to cut-point based measurement (Rowlands et al., 2018a, 2019; Fairclough et al., 2020). Examples of these metrics are: the average acceleration over 24h, the lowest acceleration over the most active hour, and the lowest acceleration over the most active half hour in a day (Rowlands et al., 2018a, 2019; Fairclough et al., 2020). The average acceleration over 24h differs from PA intensity assessment as it represents the magnitude of total PA accumulated during the recording time and was found to be positively associated with health related outcomes in children (Fairclough et al., 2019). The lowest acceleration over the most active one hour or half an hour provides a useful information about how active children were over a period of interest (in this case, the most active 60 minutes and 30 minutes) and were also found to be associated with health related outcomes in children (Fairclough et al., 2020). The advantage of cut-point free data driven acceleration metrics is that they are not based on calibration protocols that are population and protocol specific and therefore might facilitate the comparison between PA results obtained in different age groups, different populations together with outputs obtained by different accelerometer brands (Rowlands et al., 2018a, 2019; Fairclough et al., 2020). Therefore, future research assessing PA in children should present both cut-point based and cut-point free measurement of PA aspects to facilitate future comparison between different studies.

Other aspects should be considered when using accelerometers to obtain an estimate of the true habitual PA in children comprising valid wear time criteria, valid day criteria and valid week criteria. Wear time criteria have been created to distinguish between periods where an individual is not moving (e.g. sleeping, watching TV) from periods when an individual is not wearing the accelerometer (Migueles et al., 2017; Montoye et al., 2018). As for valid day criteria, at least 10 hours of valid wear time are recommended when assessing children during their wake time (Migueles et al., 2017; Montoye et al., 2018). Lastly, to obtain accurate measurement of habitual PA over the week in children (valid week criteria) it is suggested to collect PA over at least four valid days (Migueles et al., 2017; Montoye et al., 2018). It is therefore important for researchers to carefully consider aspects of accelerometer wear time, valid day and valid week criteria to obtain good estimate of children's habitual PA.

Physical activity levels in children

Despite the health benefits associated with PA, a large amount of children across the globe do not engage in the recommended guidelines of 60 minutes of moderate-to-vigorous physical activity (MVPA) per day for healthy growth and development (Griffiths et al., 2013; Konstabel et al., 2014; Roman-Viñas et al., 2016; Manyanga et al., 2019; Tanaka et al., 2020). Roman-Viñas et al. (2016) reported the percentage of children engaging in 60 min of MVPA each day assessed using accelerometry in 9-10-year-old children from 12 countries (Australia, Brazil, Canada, China, Colombia, Finland, India, Kenya, Portugal, South Africa, UK, USA) and found that the percentage of children meeting the guidelines ranged from an average of 26.5% in USA to a 61.4% in Finland (Roman-Viñas et al., 2016). A similar study evaluating MVPA using accelerometers in children aged between 2 and 10 years within several countries in Europe (Italy, Estonia, Cyprus, Belgium, Sweden, Germany, Hungary, Spain) reported that the proportion of children meeting the 60 minutes MVPA guidelines ranged from 2.0% (Cyprus) to 14.7% (Sweden) in girls and from 9.5% (Italy) to 34.1% (Belgium) in boys (Konstabel et al., 2014). Within all the aforementioned studies, boys were more likely to meet PA guidelines compared to girls (Konstabel et al., 2014; Roman-Viñas et al., 2016; Manyanga et al., 2019; Tanaka et al., 2020). Furthermore, a study presenting data from many countries all over the globe (i.e. Australia, China, Brazil, Denmark, Estonia, Norway, Portugal Switzerland, UK, USA) reported that PA in children steadily declines from early childhood (5-6 years old) toward adolescence (Cooper et al., 2015).

UK Children's PA levels are similar to what has been reported in other countries. The results from the Health Survey for England 2015, where PA was assessed using self-reported measurement, found that 22% of 5-15-year-old children met the 60 minutes PA guidelines, with 23% of the boys and 20% of the girls meeting the PA recommendations, respectively (UK Health and Social Care Information Centre, 2015). A number of studies have examined UK children's PA levels using accelerometers during the whole week or week segments. It was found that 51% of 7-8-year-old British children participating in the Millennium Cohort Study met the 60 minutes PA guidelines, where children spent a median of 60.1 minutes in MVPA (Griffiths et al., 2013). Ramirez-Rico et al. (2014) reported that 10-14 years old children from

England spent on average 48.6 minutes of MVPA during weekdays, 36.5 minutes of MVPA during weekend days and 19.6 minutes of MVPA during school time (Ramirez-Rico et al., 2014). Noonan et al. (2016) reported that that 9-10 years old children from England spent 16.5 to 30 minutes of MVPA on average during the whole week, 18.7-31.9 minutes of MVPA on average during week days, 14.2-28.1 minutes in MVPA on average during weekend days and 9.8-16.7 minutes of MVPA during school time (Noonan et al., 2016). Additionally, McLellan et al. (2018) reported that 7-12 years old boys from England accumulated on average 96.9 minutes of MVPA during the whole week, 103.9 minutes of MVPA during week days, 81.3 minutes in MVPA in weekend days and 46.1 minutes of MVPA during school time (McLellan et al., 2020). Similarly, 7-12 years old girls within McLellan et al. (2018) accumulated on average 93.9 minutes of MVPA during the whole week, 95.7 minutes of MVPA during week days, 84.3 minutes of MVPA during weekend days and 40.7 minutes of MVPA during school time (McLellan et al., 2020). Additionally, and in line with results from studies involving multiple countries, it was found that PA steadily declines from childhood towards adolescence in British children (Farooq et al., 2018). Despite the proportion of children meeting PA guidelines varying between different studies, it is worrying that a high proportion of children in UK and in many other countries do not engage in adequate levels of PA and that PA steadily drops from early childhood towards adolescence. Therefore, given that children who are physically active are also more likely to become healthy and active adults (Telama et al., 2014), it is of great importance to find strategies to increase PA and prevent PA decline at a population level.

Apart from the decline in PA with age, PA levels were found to differ based on several other factors. In particular, it was found that: girls are generally less active than boys (Cooper et al., 2015; Deng and Fredriksen, 2018; Farooq et al., 2018; McLellan et al., 2020), overweight and obese children engage in lower PA levels compared to children presenting an healthy weight (Owen et al., 2010), children with special educational needs present lower PA levels compared to their peers without special education needs (Hinckson and Curtis, 2013), children from ethnic minorities generally present lower PA than white British peers, and children from highly deprived areas display lower PA levels compared to children from more affluent areas (Noonan et al., 2016; Chang and Kim, 2017). Therefore, studies or interventions aiming to promote PA in children should account for these factors when designing strategies to increase PA or when analyzing PA outcomes.

Children from deprived areas and/or low-income families are particularly at risk of not engaging in sufficient PA for health benefits (Noonan et al., 2016; Chang and Kim, 2017). One of the reasons behind this is that children living in areas of deprivation have less opportunities to be physically active outside their home due to limited access to safe playgrounds, unsafe streets due to traffic and crime safety of the area (Noonan et al., 2016; Chang and Kim, 2017). Other factors affecting children's PA in this population include parents having limited amount of time to support and participate in PA with children because of their work schedules and domestic responsibilities, children not having access to material and resources to engage in active play, and lastly parents having limited financial resources to afford PA opportunities such as sport opportunities for their children (Chang and Kim, 2017). Therefore, it is particularly important to promote PA in children from deprived areas as they present many disadvantages compared to their peers living in wealthier areas.

School and physical education as a setting for physical activity promotion

School is considered an ideal setting to promote PA in the whole population as children from most countries go to school regularly (Hills et al., 2015; Chen and Gu, 2018). Furthermore, for many children school is the only occasion to engage in organised PA learning experiences (Hills et al., 2015; Chen and Gu, 2018). A recent review by Grao-Cruces et al.

(2020) reported that children spend on average between 14 and 61 minutes in MVPA at school, showing that children engage in a considerable amount of PA during the school day and can even meet PA guidelines during school time (Daly-Smith et al., 2020; Grao-Cruces et al., 2020). Different school components were identified as avenues for PA promotion interventions including PE, class time (e.g. classroom time, breaks between lessons), recess, time before and after school, staff involvement (e.g. staff training in promoting PA), and lastly family and community involvement (e.g. active travel, community PA events or engagement or engagement of parents as active agents within intervention to promote PA) (Erwin et al., 2013; Russ et al., 2015).

Between school intervention components, PE-based interventions was one of the preferred methods to foster PA in children (Errisuriz et al., 2018). PE is a mandatory subject within primary and secondary schools in most countries all over the world and therefore PE is an important environment to promote PA in many children (UNESCO, 2014). PE is a key occasion for children to engage in MVPA during school time and evidence suggests that children are more physically active during school days including PE than during school days not including PE (Yli-Piipari et al., 2016). The suggestion that PE plays a prominent role in promoting PA and health in children from a public health perspective is not new (Sallis and McKenzie, 1991). In line with this public health discourse, PE teachers were challenged to pursue health and fitness related goals during PE with the aim to provide high levels of MVPA during PE, and prepare children for a lifetime engagement in PA (Sallis and McKenzie, 1991; Sallis et al., 2012). This health-related focus has, however, been criticised by some researchers in the PE field, suggesting that PE should not prioritise health related outcomes (e.g. promoting PA engagement and fitness) over creating meaningful educational experiences for children (i.e. moral and social outcomes; (Fitzpatrick, 2019). Historical discussions regarding the role of PE from a public health perspective recognised that a health-related PE model should not just target more active children but it should also teach children social, cognitive and movement skills through the engagement in PA (Sallis and McKenzie, 1991; Sallis et al., 2012). This is in line with recent literature reporting that PE should play a central role in promoting physical literacy in children by supporting their affective, physical and cognitive development to foster participation in PA both during childhood and across all the life course (Edwards et al., 2017; Green et al., 2018; Shearer et al., 2018; National Assembly for Wales, 2019; UK Department of Education, 2019). Therefore, irrespectively of the main learning outcomes that teachers want to achieve during PE lessons, students should learn while engaging in high levels of PA during PE.

In line with a public health perspective, recent PE guidelines published by national and international institutions stated that children should develop a range of skills that should enable them to lead a physically active life (Table 2) (Australian Curriculum Assessment and Reporting Authority, 2013; UK Department of Education, 2013; SHAPE America, 2015; UNESCO, 2015). Furthermore, this health-related rationale led to the development of the goal to engage students in MVPA for at least 50% of PE lesson time (U.S. Public Health Service, 1991) that was subsequently adopted by several national PE organizations (Pate et al., 2006; AAHPERD, 2013; afPE, 2020). Despite the guidelines focusing on PA promotion in PE, two reviews concerning MVPA within PE in elementary schools reported that children engaged in MVPA on average for 37.4% (Fairclough and Stratton, 2006) and 44.8% (Hollis et al., 2016) of PE lessons, respectively. Furthermore, recent studies involving primary school children reported percentages of MVPA during PE ranging between 9.5% and 42.4% (Wood and Hall, 2015; Tanaka et al., 2018; Powell et al., 2019). Nevertheless, some studies demonstrated that it is feasible for children to engage in MVPA for more than 50% of the PE time, suggesting that more could be done to promote PA in PE (Hollis et al., 2016). The vast majority of studies assessing PA in PE used PA observation methods such as SOFIT and classified “walking” and “vigorous” PA behaviours as MVPA (McKenzie et al., 1996; Sallis et al., 1997; Coleman et al., 2005; Logan et al., 2015; Powell et al., 2016, 2020; Telford et al., 2016). However, it was found that classifying “walking” and “vigorous” PA behaviours as MVPA can lead to overestimation of MVPA since PA behaviours such as “slow walking” should be classified as LPA (Saint-Maurice et al., 2011; Butte et al., 2018). Therefore, future research should investigate children’s MVPA during PE using different valid and reliable methods to assess PA such as accelerometers (Saint-Maurice et al., 2011; Weaver et al., 2018a).

While PE guidelines (Table 2) suggest that children should be supported to lead physically active lives, yet there is lack of research and weak evidence of the effect of PE on children’s habitual PA due to limitations in study design and PA measurement in previous studies (Tompsett et al., 2017; Errisuriz et al., 2018). In particular, the vast majority of previous studies assessing the effect of PE on habitual PA used self-report or parent proxy questionnaires that were found to poorly estimate PA in children (Donnelly et al., 1996; Sallis et al., 1997; Manios et al., 1998; Caballero et al., 2003; Verstraete et al., 2007b; Chatzisarantis and Hagger, 2009; Sacchetti et al., 2013; Telford et al., 2016; Hidding et al., 2018; Invernizzi et al., 2019; Kokkonen et al., 2019). Therefore, future studies should assess the effect of PE interventions on PA using more accurate PA assessment methods such as device-based measurements.

Table 2. Physical education definitions and aims in different national and international organizations

Organisation: UNESCO **Resource:** Book - Quality Physical Education (QPE): guidelines for policy makers (UNESCO, 2015) **Guidelines about physical education**: "*Quality Physical Education (QPE) is the planned, progressive, inclusive learning experience that forms part of the curriculum in early years, primary and secondary education. In this respect, QPE acts as the foundation for a lifelong engagement in physical activity and sport. The learning experience offered to children and young people through physical education lessons should be developmentally appropriate to help them acquire the psychomotor skills, cognitive understanding, and social and emotional skills they need to lead a physically active life*."
Organisation: UK Department of Education **Resource:** National curriculum in England - Physical education programmes of study: key stages 1 and 2 (UK Department of Education, 2013) **Guidelines about physical education**: **"***A high-quality physical education curriculum inspires all pupils to succeed and excel in competitive sport and other physically demanding activities. It should provide opportunities for pupils to become physically confident in a way which supports their health and fitness. Opportunities to compete in sport and other activities build character and help to embed values such as fairness and respect.* *Aims* *The national curriculum for physical education aims to ensure that all pupils:* • *develop competence to excel in a broad range of physical activities* • *are physically active for sustained periods of time* • *engage in competitive sports and activities* • *lead healthy, active lives*."
Organisation: Australian Curriculum Assessment and Reporting Authority **Resource:** Australian Curriculum - Health and Physical Education | Rationale (Australian Curriculum Assessment and Reporting Authority, 2013) **Guidelines about physical education**: "*…In Health and Physical Education, students develop the skills, knowledge, and understanding to strengthen their sense of self, and build and manage satisfying, respectful relationships. They learn to build on personal and community strengths and assets to enhance safety and wellbeing. They critique and challenge assumptions and stereotypes. Students learn to navigate a range of health-related sources, services and organisations.* *At the core of Health and Physical Education is the acquisition of movement skills and concepts to enable students to participate in a range of physical activities – confidently, competently and creatively. As a foundation for lifelong physical activity participation and enhanced performance, students acquire an understanding of how the body moves and develop positive attitudes towards physical activity participation. They develop an appreciation of the significance of physical activity, outdoor recreation and sport in Australian society and globally. Movement is a powerful medium for learning, through which students can practise and refine personal, behavioural, social and cognitive skills*. *Health and Physical Education provides students with an experiential curriculum that is contemporary, relevant, challenging and physically active…"* **Resource:** Australian Curriculum - Health and Physical Education | Aims (Australian Curriculum Assessment and Reporting Authority, 2013) **Guidelines about physical education**: *"The Australian Curriculum: Health and Physical Education (F–10) aims to develop the knowledge, understanding and skills to enable students to:* *access, evaluate and synthesise information to take positive action to protect, enhance and advocate for their own and others' health, wellbeing, safety and physical activity participation across their lifespan…*"
Organisation: SHAPE America **Resource:** Report - The Essential Components of Physical Education (SHAPE America, 2015) **Guidelines about physical education**: "*Physical education is an academic subject and serves as the foundation of a CSPAP and, as such, demands the same education rigor as other core subjects. Physical education provides students with a planned, sequential, K-12 standards-based program of curricula and instruction designed to develop motor skills, knowledge and behaviors for active living, physical fitness, sportsmanship, self-efficacy and emotional intelligence*."

Interventions to increase physical activity in children during physical education

Previous research found that the majority of PE interventions were associated with increased MVPA in primary school children during PE lessons compared to children participating in usual PE classes in control conditions (Errisuriz et al., 2018). PE interventions successfully employed a wide variety of strategies to improve MVPA during PE (Table 3).

Table 3. Intervention studies where physical activity during physical education in children was assessed

Study	Sample & Baseline age	Intervention description	Country & PE Intervention Duration	PA assessment method	PA outcome
(McKenzie et al., 1996) (Luepker, 1996) (Coleman et al., 2005)	N = 9095, 8-9y N = 5106, 8-9y N = 896, 8-9y	The "CATCH" multicomponent multi-centre school-based programme comprising food service intervention, classroom curricula promoting health, health related school policy changes, and family components as well as teacher trainings to deliver the CATCH PE curriculum and use CATCH materials	USA, 2.5y USA, 3y Mexico, 3y	SOFIT SOFIT SOFIT	MVPA: INT > CON MVPA: INT > CON VPA: INT > CON
(Donnelly et al., 1996)	N = 338, 8-11y	A multicomponent intervention targeting the reduction in body mass index by involving strategies to modify the diet and PA behaviours in children including a teacher training to increase PA in PE	USA, 2y	SOFIT	SOFIT PA score: INT > CON
(Sallis et al., 1997)	N = 955, 9-10y	The "SPARK" intervention included teacher training to	USA, 2y	SOFIT	MVPA: INT > CON

(Verstraete et al., 2007b)	N = 764, 10-12y	deliver a PE component focused on promoting PA, movement skills and enjoyment in PE together with a self-management component to teach children ways to improve their PA outside school	Belgium, 2y	SOFIT Accelerometer	MVPA: INT > CON MVPA: INT = CON
(Van Beurden et al., 2003)	N = 1045, 7-10y	The “Move it Groove it” intervention included teachers professional development workshops, a buddy program for teachers to support each other, a project website containing resources for teachers and funding to buy PE equipment	Australia, 1y	SOFIT	VPA: INT > CON
(Fairclough and Stratton, 2005)	N = 30, 11-12y	An intervention to increase MVPA in PE designed for girls specifically provided by a PE expert where the intervention deliverer was provided with a set of principles and instructions to foster MVPA in PE	UK, 6 weeks	Heart rate	MVPA: INT > CON
(Miller et al., 2015)	N = 168, 11-12y	The “PLUNGE” intervention where teachers participated in a training to develop practical instruction skills, promote a mastery climate and use a game centred curriculum	Australia, 8 weeks	Pedometers	Steps/minute: INT > CON
(Logan et al., 2015)	N = 48, 7-8y	PE interventions based on a mastery and a performance motivational climate	USA, 5 weeks	SOFIT	MVPA: INT > Baseline

		provided by a PE specialist			
(Telford et al., 2016)	N = 853, 7-8y	The “LOOK study” that involved specialist-taught PE to increase student PA through inclusive, enjoyable, challenging and not threatening environment	Australia, 4y	SOFIT	MVPA: INT > CON
(Weaver et al., 2017)	N = 150, 6-9y	The “PACES” PE intervention where PE teachers participated in a training to improve MVPA in children during PE	USA, 4 months	Accelerometer	MVPA: INT > Baseline (no control group)
(Weaver et al., 2018b)	N = 823, 6-10y	A professional development training intervention for PE teacher based on the same principles used in the “PACES” intervention to improve PA in children during PE	USA, 6-7 months	Accelerometer	MVPA: INT > Baseline (no control group)
(Powell et al., 2016) (Powell et al., 2020)	N = 111, 7-9y N = 84, 5-11y	the “SHARP” interventions that included the training of teachers or coaches to embed specific principles in PE (i.e. Stretching whilst moving, high repetition of motor skills, Accessibility through differentiation, reducing sitting and standing	UK, 1y UK, 4 weeks	SOFIT SOFIT	MVPA: INT > CON MVPA: INT > CON

PE: physical education; **N:** number of participants; **y:** years**; PA:** physical activity; **MVPA:** moderate to vigorous physical activity; **VPA:** vigorous physical activity; **INT:** intervention group; **CON**: control group; **“>”:** significantly higher compared to; **“<”:** significantly lower compared to; **“=”:** no difference with.

All the interventions reported in Table 3 targeted the modification or implementation of specific aspects of teaching practices in PE and most studies involved teacher training of school staff to deliver PE, though no studies mentioned pedagogical models guiding PE delivery (Donnelly et al., 1996; Luepker, 1996; McKenzie et al., 1996; Sallis et al., 1997; Van Beurden et al., 2003; Coleman et al., 2005; Fairclough and Stratton, 2005; Verstraete et al., 2007b; Logan et al., 2015; Miller et al., 2015; Telford et al., 2016; Powell et al., 2016, 2020; Weaver et al., 2017, 2018a). Furthermore, most studies reported the improvement of children's MVPA during PE as the primary aim of the intervention and most studies targeted teaching strategies that specifically focused on increasing MVPA in PE (e.g. reducing time spent in sitting and standing, promoting PA verbally, delivering high energy expenditure activities, reducing student time off task, decreasing elimination or waiting activities, and increasing time in game activities) (Luepker, 1996; McKenzie et al., 1996; Sallis et al., 1997; Coleman et al., 2005; Fairclough and Stratton, 2005; Verstraete et al., 2007b; Miller et al., 2015; Powell et al., 2016, 2020; Telford et al., 2016; Weaver et al., 2017, 2018a). The majority of the PE interventions reported in Table 3 incorporated movement skill development as a component of PE interventions, however, only the "Move it Groove it" and "PLUNGE" interventions reported both PA and movement skills development as a primary aim of the intervention and assessed both PA and movement skills outcomes in children (Van Beurden et al., 2003; Miller et al., 2015). Similarly, to other PE interventions, also the 'Move it. Groove it' and the PLUNGE studies reported strategies to improve PA in PE (Van Beurden et al., 2003; Miller et al., 2015). More specifically, the 'Move it, Groove it' study reported that PE experts provided generalist teachers with updated strategies, resources, and knowledge in increasing PA during PE though a buddy system, however, no specific information were provided concerning these strategies (Van Beurden et al., 2003). Furthermore, the "PLUNGE" study reported the focus on "game play" activities as a key strategy to promote both movement competence development and high levels of PA during PE (Miller et al., 2015). However, there is lack of research assessing the effect of PE interventions aiming at increasing movement competence where PE deliverers are not trained to improve PA in PE as well. Therefore, it is not clear whether children's PA increase in PE interventions is due to movement learning strategies or PA promotion strategies. Furthermore, no study clarified the theoretical basis guiding the delivery of movement learning activities in PE in PA interventions suggesting that future research should fill these gaps.

Most of the interventions aiming to increase PA in PE used the System for Observing Fitness Instruction Time (SOFIT) observation tool, while only three studies involved accelerometers (Verstraete et al., 2007b; Weaver et al., 2017, 2018b), one study used heart rate monitors to assess PA (Fairclough and Stratton, 2005) and one used pedometers (Miller et al., 2015). However, SOFIT PA assessment is derived from the observation of four children only within a PE lesson and has therefore been suggested that SOFIT observation method might lead to PA estimates that are not representative of the class PA levels (Weaver et al., 2018a). Therefore, future research should employ PA assessment strategies that facilitate recording of a higher number of children within a PE lesson to make sure that PA recordings are representative of the overall PA levels of the class.

Within previous research assessing PA in PE interventions only three studies involved 5 or 6 years old children (Weaver et al., 2017, 2018a; Powell et al., 2020). Of these studies, only one evaluated the difference in PA levels during PE between an intervention and a control group (Powell et al., 2020). Therefore, future interventions should evaluate the effect of PE interventions on PA during PE in young children (e.g. 5-6 years old) participating in their first year of primary school. Furthermore, no study reported MVPA during PE in 5-6 years old children specifically using device-based methods suggesting that more research is needed to evaluate MVPA levels within PE in this population. Another limitations of previous research examining children's MVPA in PE is that many studies did not account for factors associated with MVPA in PE comprising children's sex, age and BMI, lesson content, lesson location and lesson duration (McKenzie et al., 1996; Sallis et al., 1997; Coleman et al., 2005; Miller et al., 2015; Robinson et al., 2015; Powell et al., 2016, 2020) and few studies did not account for clustering factors such as school, class or teacher even if these factors were relevant based on study design (Luepker, 1996; Powell et al., 2016, 2020). Therefore, future PE intervention studies should account for relevant variables associated with PA in PE within statistical analysis models to generate robust evidence about PE intervention effects.

Teaching practices in physical education associated with physical activity

PE teachers are responsible for transferring pedagogical approaches into practice and their actions as well as their PE lesson design has a direct impact on children's PA engagement (Weaver et al., 2016; Fairclough et al., 2018). Furthermore, teachers' expertise in PE delivery is positively associated with children's PA engagement during PE, suggesting that PE experts might employ better strategies to promote children's engagement during PE lessons compared to generalist teachers (McKenzie et al., 1993, 1995, 1997; Telford et al., 2016). Thus, collecting information about teaching practices in PE can help identify the best approaches to promote high levels of MVPA during PE and might aid understanding of why and how PE interventions affect specific outcomes in child development, including the promotion of habitual PA (Errisuriz et al., 2018). Several observation tools were developed to assess aspects of teaching PE and coaching behaviours (Weaver et al., 2016; Cope et al., 2017; Fairclough et al., 2018). The SOFIT (McKenzie et al., 1992) and the modified System for Observing Fitness Instruction Time to Measure Teacher Practices Related to Physical Activity Promotion (SOFIT+) (Weaver et al., 2016) were specifically designed to assess teaching practices associated with children's engagement in PE. More specifically, SOFIT was designed to assess children's PA levels and opportunities to become physically fit in PE lessons (McKenzie et al., 1992), while SOFIT+

was designed to assess teaching practices associated with children's PA engagement in PE (Weaver et al., 2016).

SOFIT was designed to record PA level categories comprising lying, sitting, standing walking and vigorous activity (McKenzie et al., 1992). Furthermore, the original version of SOFIT included recording of teaching aspects including *Lesson Context* (i.e. *Management*, *Knowledge*, *Physical fitness knowledge*, *Fitness*, *Skill Practice*, *Game Play*) and *Teacher Behaviours* (i.e. *Promotes Fitness*, *Demonstrates fitness*, *Instructs generally*, *Manage*s, *Observes*, *Off task*) (McKenzie et al., 1992). The original version of the SOFIT was modified to capture and record *Teacher PA promotion interaction* variables (i.e. *Promotes in-class PA*, fitness, or *motor skills*; *Promotes out-of-class PA, fitness, or motor skills*; *No, does not promote in- or out-of-class PA, fitness, or motor skills*) (Mckenzie, 2009). SOFIT+ was developed by further modifying and integrating new aspects to the SOFIT (Weaver et al., 2016; Fairclough et al., 2018). More specifically, SOFIT+ was designed to provide a more in-depth assessment of the teaching practices associated with children's MVPA during PE or coaching sessions compared to SOFIT (Weaver et al., 2016; Fairclough et al., 2018). Consequently, SOFIT+ does not involve child level PA assessment and focuses on teaching practices only. Similar to SOFIT, SOFIT+ includes the assessment of *Lesson Context* variables (i.e. *Management*, *Knowledge*, *Fitness*, *Skill Practice*, *Game Play* and *Free Play*) (Weaver et al., 2016). However, new teaching practice variables were introduced in the SOFIT+ to assess *Activity Context* (i.e. *Individual Activity*, *Partner Activity*, *Small Sided Activity*, *Whole-Class Activity*, *Waiting Activity*, *Elimination Activity*, *Girls Only Activity* and *Children Off Task*), *Teaching Behaviours* (i.e. *Instructs*, *Promotes PA*, *PA as Punishment*, *Withholding PA*, *PA Engaged*, *Off Task*) and teacher *Activity Management* (i.e. *Signalling*, *Retrieving equipment from multiple access points*, *Retrieving equipment from one access point*, *Grouping*, *Interruption Private* and *Interruption Public)* (Weaver et al., 2016; Fairclough et al., 2018). SOFIT+ can be used for outcome or process measurement of PE interventions aiming to increase MVPA in children during PE lessons and to identify best practices for MVPA promotion during PE (Weaver et al., 2016; Fairclough et al., 2018). A limitation of SOFIT+, as well as SOFIT, is that it was not designed to record aspects of learner-centred pedagogies such as activities where children are left free to explore movement experiences or aspects of teacher interaction with learners such as one to one communication that might have a different impact on the overall class engagement in MVPA compared to instructing the whole class (Dale, 1991; Nicaise et al., 2007; Weaver et al., 2016). Furthermore, the study that validated SOFIT+ in children included participants from the USA and did not evaluate the relationship between management activities and children's MVPA engagement during PE lessons (Weaver et al., 2016). Therefore, future studies should integrate relevant aspects of student-centred pedagogies within SOFIT+ and assess the cross-cultural validity of the tool in primary school children from different countries.

To date, only two intervention studies in primary school children assessed both children's PA and teaching practices associated with children's MVPA in PE using SOFIT+ (Weaver et al., 2017, 2018a). The Partnerships for Active Children in Elementary Schools (PACES) study focused on MVPA promotion in primary school PE (6-9 year-old children) and successfully increased MVPA in PE (Weaver et al., 2017). The PACES intervention involved teacher training aimed at modifying teaching practices associated with MVPA in PE (Weaver et al., 2017) based on the "LET US Play" PA promotion principles comprising: decreasing time spent in elimination activities and waiting in line, promoting small sided games, managing uninvolved children and space as well as managing equipment and rules to increase children engagement in activities (Weaver et al., 2013, 2017). More specifically, the teacher training within the PACES study focused on decreasing teaching practices associated with reduced MVPA represented by "*Elimination Activity*" and "*Children Off Task*" as well as increasing teaching practices associated with improved MVPA such as "teacher *Promotes PA* verbally" and "*Small Sided Activity*" (Weaver et al., 2017). The PACES intervention led to a significant decrease in children being off task (MVPA decreasing teaching practices) and increased verbal promotion of PA as well as small sided activities (MVPA promoting teaching practices) during PE compared to the baseline PE lessons measurements (Weaver et al., 2017). These teaching practices results provided important information to understand why the PACES intervention significantly increased children's PA in PE (Weaver et al., 2017). Similar to the PACES study, Weaver et al. (2018) conducted a PE intervention that included teacher training in the "LET US play" principles aiming to increase MVPA in PE in 6-10-year-old children (Weaver et al., 2018b). The intervention was successful at increasing MVPA promoting practices such as time in "*Motor Content*" while it reduced MVPA decreasing teaching practices such as "*Knowledge* (instruction time)", and "*Waiting Activity*" (Weaver et al., 2018b). Not surprisingly, the improvement in teaching practices was accompanied by a significant improvement in children's PA during PE compared to baseline measurements (Weaver et al., 2018b). The results obtained using the SOFIT+ helped interpret why PE interventions were successful in increasing children's PA in PE and provided useful indications for future research and PE practice. Therefore, future interventions should use SOFIT+ to assess teaching practices associated with MVPA in PE and clarify best practices to increase children's MVPA in PE.

Effect of physical education interventions on habitual physical activity in children

PE is not merely an opportunity for children to engage in PA, it is widely recognized as playing a crucial role in the development of knowledge and skills to foster their PA engagement throughout life (Table 2) (Australian Curriculum Assessment and Reporting Authority, 2013; UK Department of Education, 2013; SHAPE America, 2015; UNESCO, 2015; afPE, 2020). A number of different studies have assessed the effect of PE interventions on habitual PA in children, including a variety of intervention approaches (Table 4).

Table 4. Physical education intervention studies where habitual physical activity was assessed in children

Study	Sample & Baseline age	Intervention description	Country & PE Intervention Duration	PA assessment method	PA outcome
(Donnelly et al., 1996)	N = 338, 8-11y	A multicomponent intervention targeting the reduction in body mass index by involving strategies to modify the diet and PA behaviours in children including a teacher training to increase PA in PE	USA, 2y	Questionnaire checklist	PA score: INT < CON
(Sallis et al., 1997) (Verstraete et al., 2007a)	N = 955, 9-10y N = 764, 10-12y	The “SPARK” program including a teacher training to deliver the PE component focused on promoting PA, movement skills and enjoyment in PE together with a self-management component to teach children ways to improve their PA outside school	USA, 2y Belgium, 2y	Questionnaire Accelerometer Questionnaire Accelerometer	PA score: INT = CON Counts/hour: INT = CON MPA: INT > CON MVPA: INT > CON
(Manios et al., 1998)	N = 962, 6-7y	A multicomponent health education intervention involving teacher training, parent involvement as well as material for teachers to deliver the interventions and workbooks for children	Greece, 3y	Parent report	MVPA: INT > CON
(Caballero et al., 2003)	N = 1704, 8-9y	The “Pathways” Intervention involving 4 components comprising: teacher training to implement PE classroom curriculum, teacher mentoring, food service, PA and family involvement	USA, 3y	Questionnaire Accelerometer	PA score: INT > CON Average vector magnitude/Min: INT = CON
(Boyle-Holmes et al., 2010)	N = 1464, 9-11y	A teacher training for the implementation of a PE curriculum focused on developing knowledge	USA, 1.5y	Questionnaire checklist	4^{th} grade children

		attitudes skills and behaviours associated to lifelong PA trough progressions of movement skills			Total minutes PA: INT > CON
(Sacchetti et al., 2013)	N = 497, 8-9y	An intervention involving PE experts implementing strategies to increase PA within the classroom, during playtime and in PE thanks to enhanced duration, frequency and intensity of PA opportunities	Italy, 2y	Questionnaire	% of very sedentary children: INT < CON
(Cohen et al., 2015)	N = 460, 7-10y	The "SCORES" intervention comprising teacher professional learning, student leadership workshops and home based PA promotion tasks	Australia, 1y	Accelerometer	MVPA: INT > CON
(Jarani et al., 2016)	N = 767, 6-10y	The implementation of an exercise based PE curriculum and a game based PE curriculum by PE specialists	Albania, 5 months	Questionnaire	PA score: INT = CON
(Telford et al., 2016)	N = 853, 7-8y	"The LOOK study" that involved specialist-taught PE to increase student PA through inclusive, enjoyable, challenging and not threatening environment	Australia, 4y	Pedometer	Steps/day: INT = CON
(Bryant et al., 2016)	N = 82, 8-10y	An intervention including a combination of circuits and dancing to music activities aiming at increasing fundamental movement skills implemented during one PE lesson per week	UK, 6 weeks	Pedometer	Boys: Steps/day: INT = CON Girls Steps/day: INT > CON
(Invernizzi et al., 2019)	N = 121, 10-11y	An intervention concerning the implementation of a Multi-teaching styles approach as well as active reflection during PE provided by PE experts	Italy, 12 weeks	Questionnaire	PA score: INT > CON

(Kokkonen et al., 2019)	N = 186, 10-12y	An intervention where teachers participated in a training to deliver "Creative physical education" intervention	Finland, 1y	Questionnaire	PA score: INT = CON

N: number of participants; **y:** years**; PA:** physical activity; **MVPA:** moderate to vigorous physical activity; **PE:** physical education; **INT:** intervention group; **CON**: control group; **">":** significantly higher compared to; **"<":** significantly lower compared to; **"=":** no difference with.

Generally, the majority of studies including PE interventions aiming to increase habitual PA involved training teachers to implement teaching practices aimed at promoting child PA engagement and incorporated multi-component interventions (Donnelly et al., 1996; Sallis et al., 1997; Manios et al., 1998; Caballero et al., 2003; Verstraete et al., 2007b; Boyle-Holmes et al., 2010; Sacchetti et al., 2013; Cohen et al., 2015; Kokkonen et al., 2019). Furthermore, only a few studies reported a theoretical underpinning for PE delivery (i.e. self-determination theory, multi teaching styles approach) (Invernizzi et al., 2019; Kokkonen et al., 2019), while no study reported and described the use of specific pedagogical models guiding PE delivery. Therefore, future research should evaluate whether PE interventions guided by specific pedagogical models could affect children's habitual PA. Furthermore, few PE intervention studies included movement skills development within the intervention aims. As such, there is limited evidence about how the quality of movement learning experienced through PE influences participation in PA in primary school children (Boyle-Holmes et al., 2010; Cohen et al., 2015; Bryant et al., 2016; Engel et al., 2018).

Five intervention studies that presented positive effects on habitual PA utilised PE intervention components as part of a broader multi-component intervention (Manios et al., 1998; Caballero et al., 2003; Verstraete et al., 2007a; Sacchetti et al., 2013; Cohen et al., 2015). Wider intervention components included teacher training to deliver PE, expert PE teachers assisting the class teacher, health related classroom curricula, manuals and other materials for teachers, increased break time, classroom activity breaks, including after-school hours to promote PA, daily exercise sessions, children's self-management strategies about improving PA outside schools, parent involvement in events, providing new PE equipment and information packs and communication with parents (Manios et al., 1998; Caballero et al., 2003; Verstraete et al., 2007a; Sacchetti et al., 2013; Cohen et al., 2015). Three studies involved a PE intervention only and were effective at increasing habitual PA (Boyle-Holmes et al., 2010; Bryant et al., 2016; Invernizzi et al., 2019). This suggests that a PE intervention alone might affect habitual PA in children, and that more research is needed to clarify best PE practices to promote habitual PA. Furthermore, most of the studies where higher PA levels were observed within intervention groups compared to control groups included teacher training (e.g. teachers and PE instructors received a training to deliver theoretical sessions about health or to use specific PE teaching approaches and PE curriculum) (Manios et al., 1998; Caballero et al., 2003; Verstraete et al., 2007a; Sacchetti et al., 2013; Cohen et al., 2015). Two studies involved PE delivery from external PE experts (i.e. multi-teaching approach PE intervention; circuit and dance based activities to improve movement skills) (Bryant et al., 2016; Invernizzi et al., 2019) and one study involved both manuals and materials (SPARK PE intervention) for PE teachers as well as sessions delivered by external experts (health education component) (Verstraete et al., 2007a). In view of this, providing adequate training to the people delivering PE interventions could be an important strategy to achieve the intended intervention aims.

A significant intervention effect on habitual PA was mainly found in interventions (Multi and single component PE interventions) where PA was measured using self-report methods (Manios et al., 1998; Caballero et al., 2003; Verstraete et al., 2007a; Boyle-Holmes et al., 2010; Sacchetti et al., 2013; Invernizzi et al., 2019). Some evidence of positive intervention effects was reported in 3 studies employing device-based measurement methods (i.e. two studies presenting reduced PA decline, on study reporting increased daily steps in girls only).

However, results from self- or parent-proxy reports of PA lead to poor estimates of PA in young children (see “Physical activity assessment” section at page 40) (Warren et al., 2010; Hidding et al., 2018). Therefore, future research should employ device-based measurement (e.g. accelerometers) rather than self-report to assess the effect of PE interventions on habitual PA in children. Furthermore, only one study examined the effect of PE on habitual PA among children from Year 1 (first grade) in primary school (Manios et al., 1998; Errisuriz et al., 2018). This suggests that more research is needed to evaluate the effects of PE interventions on PA in children during their first year of primary school before the start of children’s PA decline.

Movement skill learning during physical education and effects on physical activity

International and national PE curriculum guidelines state that PE should support young children’s development of movement competence (Table 2) (Australian Curriculum Assessment and Reporting Authority, 2013; UK Department of Education, 2013; SHAPE America, 2015; UNESCO, 2015; afPE, 2020), while the importance of developing movement skills was also highlighted within the UK PA guidelines for children and young people (Davies et al., 2019). Learning a wide range of movement skills (e.g. running, jumping, catching, throwing, bouncing a ball, cycling) during early childhood will serve as a foundation for the development of more complex and specialised movement skills later on in life (e.g. javelin throw, alpine climbing, tennis forehand stroke, mountain biking, scuba diving, basketball layup) (Barnett et al., 2016). Therefore, learning foundational skills could impact on children’s PA engagement through enhancing children’s actual and perceived capability to engage in wide variety of PAs, sports and recreational opportunities (Hulteen et al., 2018). However, the development of foundational movement skills and the mastery of specialised movement skills does not happen because of growth and maturation processes alone (Gallahue et al., 2012). Children need to engage in PA to practice movement skills to improve their competence

(Gallahue et al., 2012). Furthermore, planned and developmentally appropriate movement learning experiences such as participation in PE can play a key role in improving movement competencies in children (Gallahue et al., 2012; Engel et al., 2018). In line with this, it is important to find the best strategies to foster movement development in children in order to foster their PA as well.

Stodden et al. (2008) proposed a conceptual developmental model explaining how PA could foster movement development and in turn how movement development would drive PA engagement in children (Stodden et al., 2008). The model suggested that during early childhood PA would be the main driver of movement competence development as children engaging in high levels of PA would have more occasions to develop movement competences, while the relationship between motor competence an PA would strengthen over the years (Stodden et al., 2008). Furthermore, after the transition from early to middle childhood, movement competence level is the main driver of PA engagement as children presenting a better repertoire of skills would have the capacity to participate in a wide range of activities and therefore would naturally engage in high PA levels (Stodden et al., 2008). To date, evidence has confirmed what suggested by Stodden et al. (2008) and a positive and reciprocal association between movement competence and PA was observed in children (Stodden et al., 2008; Loprinzi et al., 2015; Robinson et al., 2015; Lima et al., 2017; Utesch et al., 2018). Furthermore, reviews and longitudinal studies found evidence of a positive association between movement competence and PA, with children possessing high movement competence being more likely to engage in PA during their adolescence and adulthood (Barnett et al., 2009; Holfelder and Schott, 2014; Logan et al., 2015). Furthermore, some evidence supports the existence of a movement proficiency barrier where children with poorly developed movement competences were less likely to meet the 60 minute MVPA guidelines compared with children presenting well developed movement skills (De Meester et al., 2018). Therefore, it is of key importance to foster high PA engagement in early childhood and provide children with developmentally appropriate PA experiences to increase their movement competence.

While several studies have examined associations between movement competence and PA, there is limited evidence about how movement learning interventions could affect children's PA engagement in early childhood (Robinson et al., 2015; Engel et al., 2018). More specifically, research is needed to evaluate the effectiveness of PE interventions focusing on movement development on primary school children's PA. PE pedagogical approaches underpinned by motor learning theories from contrasting standpoints such as Linear pedagogy and Nonlinear pedagogy might lead to very different movement experiences, however, both pedagogical approaches could affect both movement competence development as well as PA engagement (Robinson et al., 2015; Tompsett et al., 2017; Rudd et al., 2020b). However, to date, no research has evaluated the effect of PE pedagogical approaches based on movement learning theories on children's PA.

Pedagogies in physical education

PE pedagogies differ from a traditional PE approach defined as 'physical-education-as-sport-technique' where learners typically engage in decontextualised practice of sport skills (Kirk, 2013). The 'physical-education-as-sport-technique' approach has been criticised for lacking a conceptual and philosophical justification as well as empirical evidence of its educational value (Kirk, 2013). Kirk (2013) stated that pedagogies in PE should be guided by theoretical and philosophical standpoints as well as empirical evidence of the educational benefit associated with the pedagogical model (Kirk, 2013). Pedagogy in PE consists of interdependent elements comprising curriculum, learning and teaching (Armour, 2011). A pedagogical model identifies learning outcomes of importance and provides theoretical and practical indications about how these learning outcomes could be best achieved through teaching practices and curriculum alignment (Armour, 2011). PE approaches based on pedagogical models can be highly beneficial for practitioners in the field as well developed models already exist in the literature that can guide PE practice to achieve and prioritise different valuable learning outcomes (Kirk, 2013; Metzler, 2017). Different pedagogical models used in PE include “Sport education”, developed to create competent, literate and enthusiastic sport people (Siedentop, 1994); “Teaching Games for Understanding”, which concerns the design of games activities to enable learners to comprehend the key features and principles of the games examined (Werner et al., 1996); “Cooperative Learning”, which represents a model to teach diverse content through activities where students work together (Dyson and Casey, 2012); “Personal and Social Responsibility”, which aims to promote values, character, responsibility, and life skills in PE (Pozo et al., 2018), “Health-based Physical Education” providing models to help learners value physically active lifestyles to enhance their health (Haerens et al., 2011); and “Critical pedagogy” whereby learners are invited to reflect on themes such as equity, identity and justice through PE (Fitzpatrick, 2019). Furthermore, PE pedagogical models that focus on the improvement of movement competences have also been developed such as Linear pedagogy and Nonlinear pedagogy (described below) that are based on movement learning theories (Chow et al., 2011; Metzler, 2017). In view of the positive association between movement competence and PA in children, Linear and Nonlinear pedagogical models could potentially have a significant impact on PA behaviours in children, however, there is currently a lack of research assessing the effect of these pedagogical approaches on children’s PA engagement.

Linear pedagogy

Linear pedagogy is based on the Information Processing Theory (Schmidt, 1975) about learning. Information Processing theory explains that specific inputs (sensory inputs and desired movement outcomes) experienced by learners are elaborated together with previous experiences before commencing the action and together with the sensory feedback collected during the action (Schmidt, 1975). This process leads to the production of specific movement outcomes and learning outcomes (schemas and skill learning) (Fitts and Posner, 1967; Schmidt, 1975). From this perspective, providing learners with a set of movement experiences of increasing difficulty should lead to a linear learning progression through cognitive stages (cognitive, associative, autonomous), where the improvement in movement proficiency is accompanied by a reduction in cognitive processing while performing (Fitts and Posner, 1967). Furthermore, Linear pedagogy is characterized by a teacher-centered approach consistent with a direct instruction model (Metzler, 2017).

Linear pedagogy is therefore based on the premise that learners engage in a task of increasing difficulty within a planned didactical progression following the rationale that providing children with specific inputs represented by movement tasks will lead to specific movement outputs (Metzler, 2017). In a Linear pedagogy perspective of movement learning, students should learn the optimal movement patterns to perform movement skills correctly (e.g. throwing, catching and jumping) and all learners should conform to these idealistic movement patterns (Gallahue et al., 2012). The identification of optimal movement skills is the result of a complex process integrating the knowledge achieved by experts in each discipline, the evolution of performance throughout the years, the observation of performance in top-level athletes and the understanding of biomechanics and physiology (Gallahue et al., 2012). Teaching the optimal movement skills is considered more time efficient and effective than waiting for students to learn by trial and errors as the former teaching strategy would prevent learners from reiterating movements that are considered detrimental for a performance (Metzler, 2017). Therefore, in Linear pedagogy approaches movement variability within a task is seen as detrimental for learning as it is a source of error and should be reduced (Metzler, 2017).

Sport skills or other discipline specific skills (e.g. dance moves) usually comprise complex combinations and/or sequences of different movements (Gallahue et al., 2012). Performing a new and complex movement skill might be too challenging for a beginner (Guadagnoll and Lee, 2004). In a Linear pedagogy perspective, the aim of teachers is to simplify the movement skills to match learners' abilities. A key strategy to simplify movement skills is to divide them into smaller movement phases and practice the different phases separately (Gallahue et al., 2012).

Within Linear pedagogy, instruction time is considered a key moment to provide learners with essential information about the task to perform and facilitate performance (Rival et al., 2003; Ong et al., 2010). However, verbal instruction alone might be misinterpreted or create confusion in beginners and particularly in young children. Therefore, teachers adopting a Linear pedagogy approach provide a visual demonstration of a task before learners start practicing it (Hebert and Landin, 1994; Weeks and Anderson, 2000). Verbal instruction of the task could be accompanied or followed by a visual demonstration that could be performed by teachers or learners presenting high skills or other experts (e.g. video recordings of expert performing the task required) (Zetou et al., 2002).

The repetition of a task is also a fundamental aspect of a Linear pedagogy approach to foster learning and skill development (Metzler, 2017). Research confirmed that practicing a task multiple times is fundamental to foster its retention and improve performance (Adams, 1987; Magill, 2007). Teachers also provide corrective feedback to the learners in order to facilitate their learning process and avoid the reiteration of errors (Weeks and Kordus, 1998; Sullivan et al., 2008). Type, timing and frequency of feedback may vary depending on the situation. As concerns the type, feedback could consist in praising or correcting the learner and it could be verbal or nonverbal (Metzler, 2017).

A game or performance situation might represent a really challenging experience for a beginner (Guadagnoll and Lee, 2004; Metzler, 2017). For example, a child that is not able to dribble might find it too difficult to play a basketball match. Therefore, in a Linear pedagogy approach teachers should foster the improvement of skills that will allow learners to be successful in a game or sport performance situation and such situations should only be proposed after an adequate amount of practice of related skills (Metzler, 2017). In turn, experience of success during these performances could help children foster motivation towards PA and sport (Peers et al., 2020).

The "Challenge point Framework" and "Gentile's taxonomy" are examples of methodologies to design learning progressions of increasing difficulty within a Linear pedagogy approach (Adams, 1999; Guadagnoll and Lee, 2004). Gentile's taxonomy concerns a methodology to classify the difficulty of a specific tasks (Adams, 1999). Gentile's taxonomy comprises 4 factors characterizing movement tasks and each factor comprises two opposite conditions (Adams, 1999):

1. Body; Conditions: stability or transport.
2. Object manipulation; Conditions: no object manipulation or object manipulation.
3. Motion (environment); Conditions: stationary environment or moving environment.
4. Intertrial variability; Conditions: no intertrial variability or intertrial variability.

Using a combination of these factors, the Gentile's taxonomy table was developed (Supplementary material 1) to enable teachers to classify all the movement tasks based on their difficulty (Adams, 1999). The difficulty of the tasks increases moving from the right to the left and from the top to the bottom of the table.

Similar to Gentiles' taxonomy, the Challenge point framework provides indications about how to classify the difficulty of a task and additionally it provides guidance about how to personalize difficulty of task progressions for each individual child (Guadagnoll and Lee, 2004). The challenge point framework is based on the assumption that learning is linked with the amount of information available and interpretable for an individual (Guadagnoll and Lee, 2004).

Information consist in all those factors that should be considered while performing a movement such as instructions, space, weight, speed, timing, sequences, and the object's position (Guadagnoll and Lee, 2004). Sources of information available during and after each attempt to solve a problem are recalled and form the basis for learning, which is defined as a relatively permanent improvement in skill that results from practice (Guadagnoll and Lee, 2004). Learning is strongly linked to the amount of information that a learner is able to access using the senses and to integrate and process using nervous system (Guadagnoll and Lee, 2004). Therefore, a learning progression should be developed using the following 3 principles:

1. Learning cannot occur in the absence of information (Guadagnoll and Lee, 2004).
2. Learning will be retarded in the presence of too much or too little information (Guadagnoll and Lee, 2004).
3. For learning to occur, there is an optimal amount of information, which differs as a function of the skill level of the individual and the difficulty of the to-be-learned task (Guadagnoll and Lee, 2004).

In relation to the third principle, teachers should consider that two types of difficulty can be identified and taken into account: nominal difficulty and functional difficulty (Guadagnoll and Lee, 2004). Nominal task difficulty consists of the constant amount of task difficulty, regardless of who is performing the task and under what conditions it is being performed (Guadagnoll and Lee, 2004). Functional task difficulty refers to how challenging the task is in relation to the skill level of the individual performing the task and the conditions under which it is being performed (Guadagnoll and Lee, 2004).

Developing movement skills though a Linear pedagogical approach could lead to the formation of foundational and specialised movement skills in children that in turn could affect PA engagement in children. However, despite the Linear pedagogy principles described above being widely used in current PE practice (e.g. direct instruction model), there is a lack of empirical research regarding how Linear pedagogy could affect different outcomes in PE. This could be due to traditional research being focused on PE outcomes (health and PA) rather than on the quality of the processes to achieve intended PE goals (Errisuriz et al., 2018). Evaluating PE approaches based on clear and defined pedagogical principles might help clarify best practices for PA promotion in PE. Therefore, future research should investigate how PE guided by Linear pedagogy could affect PA outcomes.

Nonlinear pedagogy

Nonlinear Pedagogy was developed and constructed upon Ecological Dynamics theories of embodied cognition and learning (Araújo et al., 2006; Warren, 2006; Chow et al., 2011). From an Ecological Dynamics theoretical standpoint learners are seen as complex neurobiological systems in mutual and reciprocal synergy with the environment that learn through perception and action coupling processes (Araújo et al., 2006; Warren, 2006; Chow et al., 2011). In this perspective learners' actions are seen as adaptive and goal directed behaviors constrained by neurobiological-environmental factors while learning does not follow a cause-effect proportionality principle meaning that the same learning experiences might lead to very diverse movement exploration and learning outcomes in different individuals (Chow et al., 2011). Therefore, Nonlinear pedagogy involves a child-centered PE approach where teachers are seen as designers of learning experiences (Chow and Atencio, 2014). Furthermore, the main focus of Nonlinear pedagogy is to provide learners with the freedom to explore carefully designed learning environments that will lead to constraint led synergy formation and will result in the performance of functional and goal oriented movement solutions (Chow, 2013).

Nonlinear pedagogy involves 5 key principles to guide the design of learning experiences and channel the emergence of individual goal-oriented behaviours (Chow, 2013; Correia et al., 2019):

- The manipulation of constraints.
- Learning in a Representative design.
- Developing information-movement coupling.
- Fostering movement variability.
- Fostering an external focus of attention.

A central aspect of a Nonlinear approach is that movement skill learning should take place during activities that are representative of the specific activities or sport disciplines were the skills should be applied (Chow, 2013; Correia et al., 2019). A representative design is fundamental to establish affordances, defined as opportunities for action (Fajen et al., 2008), that are functional to achieve goals that are specific to an activity or sport (Chow, 2013). An example would be that basketball skills should be learnt within activities that are representative of a basketball game rather than within decontextualized drills. This should be done to create the most adequate conditions for learners to develop discipline specific, functional, and goal-oriented movement skills through their movement exploration processes. However, certain discipline specific movement skills (e.g. bouncing while running) might be very difficult to master for a beginner when applied to dynamic situations (e.g. basketball match) as affordances (opportunities for actions) are limited by children's individual characteristics and capacities. Therefore, teachers should modify constraints to make it easier for learners to explore movement solutions in a representative design (Chow and Atencio, 2014). For example, small-sided games could be employed where attackers are put in a condition of advantage (e.g. higher number of attackers) in order to easily practice sport specific skills (Chow et al., 2007; Chow and Atencio, 2014).

Another key aspect of Nonlinear pedagogy is that teachers should manage constraints to channel learning experiences, rather than provide students with detailed instructions and demonstrations about how to perform a task (Chow, 2013; Correia et al., 2019). It is necessary for teachers to know essential aspects of the activities or sports disciplines to select relevant constraints and create functional affordances to guide exploration towards specific learning goals or to foster divergent exploration of movement possibilities (Correia et al., 2019). When designing learning experiences teachers can manipulate task and environmental constraints and consider how these factors would interact with individual constraints (Chow et al., 2011). Task constraints can include aims, rules, complexity of the task, duration of a task and specific limitations in the use of elements within the environment (Correia et al., 2019). Environmental constraints concern physical aspects of the environment such as temperature, weather, type of surface, distribution of objects in the space but also social aspects such as the interaction with peers, with the teacher or with other people involved in a lesson as well as the educational climate created by the teacher (Correia et al., 2019). Lastly, individual constraints concern the different characteristics of each individual comprising physiological, psychological and cognitive aspects together with capacities and previous experiences of an individual such as strength, fitness, motivation, self-perception, confidence and skills (Correia et al., 2019).

A further Nonlinear pedagogical principle is the development of information-movement coupling consisting in the continuous creation of functional affordances within the circular process of perception-action leading to the emergence of goal-directed behaviors (Chow, 2013). This principle is in line with the idea that actions are adaptive, and goal directed behaviors are constrained by neurobiological-environmental factors while learning emerges from a continuous process of perception action (Chow et al., 2011). In this perspective, teachers design tasks where learners practice movement skills in their entirety as they emerge from the interaction between individual and environment rather than designing task where movement skills are broken-down into sub-components and practiced within drills (Chow, 2013; Correia et al., 2019). The information-movements coupling principle is strongly linked with the principles of managing constraints and representative design learning as the way teachers design tasks influences the perception-action processes enacted by learners.

Fostering functional variability during movement during tasks is another key principle of Nonlinear pedagogy (Chow, 2013; Correia et al., 2019). Increasing variability in movement practice should encourage learners to explore a variety of movement solutions that are functional to the changing situations (Chow, 2013).

Lastly, fostering an external focus of attention is another principle in Nonlinear pedagogy (Chow, 2013; Correia et al., 2019). Fostering an external focus means that learners should focus on the task that they have to accomplish (e.g. hitting a target) or on the environment (e.g. position of the opponents) rather than on their movement (e.g. how much they flex and extend their arm to throw a ball to a target).

From a Nonlinear pedagogical perspective, teachers should not provide instructions to learners explaining how to reach goals. Instructions should clarify the goals within a task and should set constraints (Correia et al., 2019; Rudd et al., 2020a). Similarly, feedback should not be used to provide learners with solutions to movement problems or strategies to reach a goal (Correia et al., 2019; Rudd et al., 2020a). Feedback should point learners to the exploration of different movement solutions and to the identification of new affordances within the environment that could help learners achieving specific goals (Correia et al., 2019; Rudd et al., 2020a). In line with this, teachers should not provide visual demonstrations that serve to provide an image of the ideal skill or technique to be performed. Demonstrations could be used to enhance students reflection and exploration of new movement possibilities (Correia et al., 2019; Rudd et al., 2020a). The observation of other learners could also serve as a prompt to explore movement possibilities (Rudd et al., 2020a). Questioning is another key strategy used in Nonlinear pedagogy to channel perception action coupling processes in learners (Correia et al., 2019; Rudd et al., 2020a). For example, when the teacher notices that a student keeps using the same movement strategies with scarce success the teacher might use questioning to help find different movement solution (e.g. “How many ways can you find to move on this mat?”) or to facilitate reflection on how to reach a goal (e.g. “How can we make it easier to hit the target with the bat?”)

Previous research evaluated the effect of Nonlinear pedagogy on aspects such as decision making in sport, perceived competence, autonomy, relatedness, motivation towards PA engagement and finally tactical behaviors in sports, however, to date, no study has assessed the effect of nonlinear pedagogy on PA engagement (Lee et al., 2017; Moy et al., 2019; Pizarro et al., 2019; Raposo et al., 2019). Several authors suggested that Nonlinear pedagogy could support children’s motivation towards PA engagement, which in turn might positively affect PA levels in children compared to traditional directive teaching approaches (Moy et al., 2016; Lee et al., 2017; Rudd et al., 2020b). In view of this, future research should clarify whether Nonlinear pedagogy might affect PA in children.

Literature review summary

This literature review has highlighted that a large proportion of children both in the UK and in many other countries do not engage in the recommended minutes of MVPA per day associated with healthy growth and development. In view of this, the necessity of accurate methods to assess PA as well as strategies to increase PA in children on a large scale were underlined. School was identified as a key environment to promote PA on a population level. More specifically, it was explained that PE could play a unique role in both engaging children in high levels of MVPA during PE classes and fostering movement skills enabling children to enhance their participation in PA. Furthermore, it was underlined that teaching practices and pedagogical approaches employed during PE can have an important impact on children PA levels both in PE and during everyday life. However, little is known about the effect of pedagogies in PE on children’s PA. Therefore, research providing a deeper understanding about the role of PE intervention guided by pedagogies could inform future PE delivery and school interventions aiming at increasing aspects of PA in children.

Aims of this thesis

The aim of this PhD thesis is to examine how different PE pedagogies (Linear and Nonlinear pedagogies), underpinned by movement learning theories, might affect PA during PE and habitual PA in the first year of primary school children (5-6 years old). This aim will be achieved through the objectives of each study included in this study.

Study 1 (chapter 3): Development of raw acceleration cut-points for wrist and hip accelerometers to assess sedentary behaviour and physical activity in 5–7-year-old children. Study 1 aims:

- To validate PA and SB raw accelerometer cut-points for hip and wrist ActiGraph GT9X accelerometers in 5-7 years old children.
- To compare the accuracy of hip and wrist cut-points for ActiGraph GT9X accelerometers to select the most suitable method to measure PA intensities in 5-7 years old children with the other studies of this thesis.

Study 2 (chapter 4): Validation of modified SOFIT+: Relating physical activity promoting practices in physical education to moderate-to vigorous physical activity in 5-6 year old children. Study 2 aim:

- To assess validity and reliability a modified version of the System for Observing Fitness Instruction Time to Measure Teacher Competencies Related to Physical Activity Promotion (SOFIT+).

Study 3 (chapter 5): Teacher physical activity promoting practices and children's physical activity within physical education lessons underpinned by motor learning theories (SAMPLE-PE). Study 3 aims:

- To assess children's MVPA in PE within Linear Pedagogy and Nonlinear pedagogy and to compare this to current practice within PE delivery in primary schools.
- To assess teaching practices associated with PA in PE within Linear Pedagogy and Nonlinear pedagogy and to compare this to current practice within PE delivery in primary schools.

Study 4 (chapter 6): Effect of Linear and Nonlinear pedagogy physical education interventions on children's physical activity: a cluster randomized controlled trial (SAMPLE-PE). Study 4 aim:

- To evaluate the effect of PE interventions guided by Linear pedagogy and Nonlinear pedagogy intervention on children's habitual PA over the whole week and different segments of the week compared to the control group (current practice in PE) in 5–6-year-old children.

Ethics

Ethical considerations should be made when doing research involving human subjects, and special measures should be considered when including children as reported within the ethical principles underlying the Declaration of Helsinki (World Medical Association, 2013). More specifically:

- Research involving humans should be conducted by individuals presenting appropriate ethics and scientific education, training and qualifications (Supplementary material 2) (point number 12 Helsinki declaration) (World Medical Association, 2013).

- In order to guarantee safety of vulnerable groups such as children, measures should be taken (point number 19 Helsinki declaration) (World Medical Association, 2013). An example could be that only people presenting valid clearance from Disclosure and Barring Service should be allowed to interact with the children participating research projects.
- The research protocols concerning studies involving humans should be submitted and approval granted by the University Research Ethics Committee (point number 23 Helsinki declaration) (World Medical Association, 2013).
- Potential participants should be adequately informed about relevant aspects of a research project before being requested to provide consent to participate in a study (Points 25 and 26 Helsinki Declaration) (World Medical Association, 2013).
- Participants should provide informed consent before the beginning of any research project (Points 25, 26, 27 Helsinki Declaration) (World Medical Association, 2013).
- Participants should be made aware that they can windrow from a research project at any point without incurring in any problem (Points 26 and 31 Helsinki Declaration) (World Medical Association, 2013).
- For subjects like children who are not capable to provide informed consent, researchers should seek informed consent from the legally authorised representatives such as parents or guardians (Points 25, 26, 27, 28 and 29 Helsinki Declaration) (World Medical Association, 2013).
- For subjects like children who are not capable to provide informed consent but can provide assent, researchers should seek for children's assent as well as informed consent from the legally authorised representatives (Points 25, 26, 27, 28 and 29 Helsinki Declaration) (World Medical Association, 2013)

- Every precaution should be made to protect the privacy and confidentiality of data collected (Points 26 and 31 Helsinki Declaration) (World Medical Association, 2013). All information about participants, including results should be treated with the strictest confidentiality (Point 24 Helsinki Declaration) (World Medical Association, 2013).

Chapter 3: Study 1

Development of raw acceleration cut-points for wrist and hip accelerometers to assess sedentary behaviour and physical activity in 5-7 year old children

This study has been published in the *Journal of Sport Siences*: **Crotti, M.,** Foweather, L., Rudd, J. R., Hurter, L., Schwarz, S., & Boddy, L. M. (2020). Development of raw acceleration cut-points for wrist and hip accelerometers to assess sedentary behaviour and physical activity in 5–7-year-old children. *Journal of Sports Sciences*, *38*(9), 1036–1045. https://doi.org/10.1080/02640414.2020.1740469

Thesis studies map: Chapter 3

Study	Objectives
Study 1: Development of raw acceleration cut-points for wrist and hip accelerometers to assess sedentary behaviour and physical activity in 5-7 year old children	• To validate PA and SB raw accelerometer cut-points for hip and wrist ActiGraph GT9X accelerometers in 5-7 years old children. • To compare the accuracy of hip and wrist cut-points for ActiGraph GT9X accelerometers to select the most suitable method to measure PA intensities in 5-7 years old children in this thesis.
Study 2: Validation of modified SOFIT+: relating physical activity promoting practices in physical education to moderate-to-vigorous physical activity in 5–6 year old children.	• To assess validity and reliability of a modified version of the System for Observing Fitness Instruction Time to Measure Teacher Competencies Related to Physical Activity Promotion (SOFIT+).
Study 3: Teacher physical activity promoting practices and children's physical activity within physical education lessons underpinned by motor learning theory (SAMPLE-PE)	• To assess children's MVPA in PE within Linear Pedagogy and Nonlinear pedagogy and to compare this to current practice within PE delivery in primary schools. • To assess teaching practices associated with PA in PE within Linear Pedagogy and Nonlinear pedagogy and to compare this to current practice within PE delivery in primary schools.
Study 4: Effect of Linear and Nonlinear pedagogy physical education interventions on children's physical activity: a cluster randomized controlled trial (SAMPLE-PE)	• To evaluate the effect of PE interventions guided by Linear pedagogy and Nonlinear pedagogy on habitual PA over the whole week and different segments of the week compared to the control group (current practice in PE) in 5–6-year-old children.

Thesis context

The decision to validate new cut-points for PA assessment using GT9X ActiGraph devices in children was due to the following reasons: 1) accelerometers are one of the most widely used methods to assess PA in children (see literature review sections "Physical activity assessment" at page 40 and "Physical activity assessment using accelerometers" at page 44); 2) the need to assess PA in a moderate sample of children aged between 5-7 years within study 2 (chapter 4), study 3 (chapter 5), study 4 (chapter 6) of this thesis; 3) The availability of GT9X ActiGraph devices at Liverpool John Moores University; 4) the lack of raw acceleration cut-points to assess SB and PA intensity levels in 5-7-year-old children using ActiGraph GT9X devices.

Introduction

Accelerometers are the most widely used devices to assess physical activity (PA) and sedentary behaviours (SB) in children and have proved to be a feasible method to assess children on a large scale (Atkin et al., 2012; Cain et al., 2013). For many years, hip-worn accelerometers were the preferred devices for PA assessment (Trost et al., 2005). A major problem with hip-worn devices is poor compliance, which has been attributed to discomfort whilst wearing or forgetting to wear the devices after removal (Fairclough et al., 2016). However, it was reported that a 24h wear time protocol with hip monitors can lead to high levels of compliance (Tudor-Locke et al., 2015). More recently, researchers have used wrist-worn accelerometers as they obtain better wear compliance (Fairclough et al., 2016; McLellan et al., 2018) and are suitable for 24-h per day recording, allowing sleep-time assessment (Morgenthaler et al., 2007; Fairclough et al., 2017). A further advantage of wrist-worn accelerometers is that they are more sensitive to upper body movement, considered as a significant component of children's PA (Fairclough et al., 2016).

Traditionally, accelerometer output was reduced to proprietary units defined as "counts" (Troiano et al., 2014). However, comparing PA and SB estimates across studies that have used different devices brands is problematic because of the brand specific data processing algorithms used (Chen and Bassett, 2005). Consequently, a methodological harmonisation was recommended involving the use of raw acceleration signals rather than counts, regardless of the device brand (van Hees et al., 2016). Raw signals consist of gravitational accelerations assessed at sample frequencies typically above 10Hz. The Euclidean Norm Minus One (ENMO), calculated using the R GGIR package, is emerging as the most frequently used metric when processing raw acceleration data generated from the most commonly used triaxial accelerometers (ActiGraph, GENEActiv and Axivity) (Bakrania et al., 2016; Migueles et al., 2019). The use of raw acceleration metrics such as ENMO have the potential to facilitate comparisons between different brands and wear sites (Fairclough et al., 2016) and to increase researchers' control over data processing. PA and SB intensity cut-points derived for use with ENMO data have been developed for the ActiGraph accelerometers for older children and adults (Hildebrand et al., 2014, 2017). Due to the characteristic intermittent nature of the movement behaviours during childhood and in view of the differences in movement dynamics observed in different age groups it is fundamental to create age specific cut-points (Bailey et al., 1995; Hausdorff et al., 1999). However, no calibration study has established raw acceleration cut-points for ActiGraph devices to assess PA or SB in 5-7 year old children.

The majority of previous calibration studies have been performed in laboratories and involved equipment such as treadmills or indirect calorimetry that could affect children's movement patterns and gait (de Almeida Mendes et al., 2018). Concerns have been raised about the ecological validity of such settings and it is has been recommended that future calibration studies should involve activities that are representative of free-living PA (Crouter et al., 2015). Additionally, calibration studies should consider accelerometers' limitations in assessing SB based on the absence of or low levels of acceleration and distinguishing stationary activities such as standing stationary from SB (Aguilar-Farías et al., 2014; Hildebrand et al., 2017).

A further consideration in developing cut-points concerns the statistical techniques used to identify and validate intensity thresholds. Calibration studies have typically used Receiver Operating Characteristic (ROC) curve analysis for the calculation of SB and PA intensity cut-points from raw accelerometer data (de Almeida Mendes et al., 2018). Intensity thresholds were typically derived by coding and grouping all the accelerations recorded during the calibration protocol into binary indicator variables (0 or 1) based on the observed or measured activity level (de Almeida Mendes et al., 2018). However, the proportion of data from each activity level (e.g. SB, LPA, MPA and VPA) used in ROC analysis plays a key role in determining PA and SB cut-points and in some case could lead to low accuracy in SB and PA assessment. For example the presence of a high proportion of SB acceleration in the ROC analysis dataset could lead to LPA, MPA and VPA cut-points that are too low to accurately classify the behaviour (Zhou et al., 2011). In light of this, alternative statistical procedures that could lead to increased diagnostic accuracy should be evaluated. The use of 'pairs' of activity levels in ROC analysis (e.g. SB versus LPA) rather grouped activities (i.e. SB versus LPA, MPA and VPA) has the potential to account for disproportions of data in different activity levels and might lead to improved diagnostic accuracy. However, to date, no study has evaluated the diagnostic accuracy of SB and PA cut-points calculated by ROC curve analysis using 'pairs' of activity levels.

In view of the gaps in the literature presented above, this study aimed to develop and validate raw acceleration cut-points for the estimation of SB and PA in 5-7-year-old children using ActiGraph devices, and to compare different methods of cut-point calculation.

Methods

Design and participants

The study received institutional research ethics committee approval (17/SLN/004). After school gatekeeper consent was obtained from the headteacher of a single primary school in a metropolitan city in North-West England, parent/carer consent and child assent forms were distributed to potential participants (n = 60) aged between 5 and 7 years old and taken home to parent/carer. As a result, 49 children agreed to take part in the study. Data collection for the study took place between November-December, 2017.

Data collection and procedures

All the participants were invited to take part in a standardised activity protocol and to be video-recorded during school recess. Data collection took place in the school gymnasium and playground to mimic free-living conditions and increase the ecological validity of the study protocol. Children's stature (The Leicester Height Measure, Child Growth Foundation, Leicester, United Kingdom), sitting stature and waist circumference to the nearest 0.1cm together with mass to the nearest 0.1kg (model 760, Seca, Hamburg, Germany) were measured using standard procedures (Dettwyler, 1993). All measurements were taken twice, with a third measurement taken if the first two differed by more than >1%. Body mass index (BMI) was calculated from stature and mass. Children self-reported their dominant hand and additionally they were asked to write their name on a paper so researchers could double check hand dominance.

Activity monitors

Participants were fitted with an ActiGraph GT9X Link on both wrists and on the right hip to evaluate whether one of the wearing positions was leading to higher accuracy in SB and PA assessment. Participants wore the three accelerometer devices throughout the data collection session. The GT9X was set to record at 100Hz and measured acceleration in a range of ±8g on x, y and z axes. Data were downloaded in 1 s epochs.

Direct observation

There is no universally accepted gold standard for PA measurement as each PA assessment method presents strengths and limitation (Hills et al., 2014; Aparicio-Ugarriza et al., 2015). Hence, direct observation was chosen as the criterion reference for the classification of SB and PA levels in this study as it is considered the most appropriate method to assess rapid changes in PA behaviours in free living conditions, typical of this age group, it does not involve equipment that might impair children's normal movements (Bailey et al., 1995; Cox et al., 2020) and it was used for calibration purposes in previous studies (Mackintosh et al., 2012; Johansson et al., 2016). Consequently, children's SB and PA were assessed using direct observation during the standardised activity protocol and during recess.

Calibration protocol

The activity protocol lasted around 60 minutes in total, took place in the school hall during usual lesson time, and involved three participants at a time, rotating between 10 different tasks (Table 5). The selection of the tasks was informed by previous calibration studies in this age group (Mattocks et al., 2007; Evenson et al., 2008; Beets et al., 2011; Mackintosh et al., 2012; Phillips et al., 2013; Hänggi et al., 2013; Schaefer et al., 2014; Hildebrand et al., 2014, 2017; Kim et al., 2014; Johansson et al., 2015, 2016; Chandler et al., 2016; Duncan et al., 2016; Roscoe et al., 2017), by observing children's typical recess play activities, and through consulting primary school teachers. Tasks were selected to encompass each activity intensity (SB, LPA, MPA and VPA) and were designed to simulate children's free-living PA and SB as accurately as possible. Four SB (Lying while watching TV, sitting while colouring, sitting and play with a tablet and playing with LEGO), one LPA (passive standing), two MPA (walking briskly together, throwing and catching) and three VPA (running, obstacle course run and hopping) activities were included in the protocol. The intensity of each activity in the protocol was classified using METs as reported in the youth compendium of physical activities (Butte et al., 2018). The most widely accepted intensity thresholds were used to classify the activities: SB (≤1.5METs), LPA (≥1.5–<3METs), MPA (≥3–<6 METs), VPA (≥ 6 METs) (Saint-Maurice et al., 2016).

Table 5: Standardised activity protocol

Sedentary behaviours	
Lying while watching TV	Lie comfortably on a mat while watching an age appropriate television programme or movie for 10 minutes.
Sitting while colouring	Colouring exercise while sitting at a table for 5 minutes.
Sitting playing with a tablet	Play games on a tablet while sitting on a chair for 5 minutes.
Playing with LEGO	Sit or lie on the floor while playing with Lego for 5 minutes.
Light physical activity	
Standing while watching TV	Stand and watch a video for 5 minutes.
Moderate physical activity	
Walking briskly self-paced	Walk briskly for 2 minutes, at a self-selected pace around a designated track or circuit. A researcher walked with the child encouraging him/her to maintain the pace.
Throwing and catching	Child and researcher passed the ball to each other continuously for 2 minutes.
Vigorous physical activity	
Running	Run for 2 minutes, at a self-selected pace around a designated track or circuit.
Obstacle course	Run for 2 minutes on a course around cones. This course was designed to mimic typical run/chase type activities and involved slalom, dodging tasks and fast changes of direction.
Hopping	Complete a hopscotch course for 2 minutes.

The activities were ordered into three different activity protocols and participants were randomised to one of the protocols. The three protocols were designed to allow three children to complete the protocol simultaneously. Children had 2 minutes rest after MPA and VPA tasks in line with previous accelerometer calibration studies (Hänggi et al., 2013; Phillips et al., 2013). Additionally, children were asked whether they needed more rest before starting each activity to make sure they fully recovered before commencing the next activity. Researchers independently conducted live direct observations of children through the protocol, which involved continuously instructing and supervising children to ensure they were ‘on task’, and recording the start time and end times of each activity.

Recess observation

Recess was included in the study protocol to capture children's behaviours during free-living conditions. Children were asked to participate in school recess as normal whilst wearing the devices. Recess took place between 10:20 and 10:40 in the morning and then again between 11:50 and 12:35 after lunch time. Each researcher video-recorded one child for a period of 10 minutes during either morning or lunchtime recess. Based on previous studies measuring activity levels during recess and previous observations of children's recess in the school involved, it was expected that children would spend the highest proportion of recess in LPA and a progressively lower amount of time in MPA, VPA respectively (Baquet et al., 2014). Behaviours during recess were assessed and classified on a second-by-second basis (in order to match accelerometery 1 s epochs) using the Youth compendium of physical activities (Butte et al., 2018). Before proceeding with the video analysis, the research team analysed three randomly selected video-recordings jointly in a single group session where behaviour classification was discussed until unanimous consensus was reached. Subsequently, one researcher (represented by me, the author of this PhD thesis) classified children's recess behaviours second-by-second based on the activities and METs reported in the Youth compendium of physical activities (SB: ≤1.5METs, LPA: >1.5&<3METs, MPA: ≥3&<6 METs, or VPA: ≥ 6 METs) (Butte et al., 2018). Uncertainties with the classification of children's behaviours that emerged during analysis were discussed and resolved with the research team by consensus.

Data analysis

ActiGraph accelerations were downloaded and converted to .csv format data using Actilife software (ActiLife v6.13.3). Subsequently, the package GGIR version 1.11-0 from R software version 3.2.5 (R Foundation, www.r-project.org) was used to process raw data and calculate average ENMO accelerations for each 1 second epoch. As a result, csv documents presenting ENMO and related timestamps were produced. Acceleration data were then paired with SB and PA observation data. The first and last 15 seconds of each task in the activity protocol were deleted to account for possible start and end time imprecision, transition time delays, and irregular movement patterns, as well as to control for learning effect and fatigue. Only data from participants that completed both the standardised protocol and observation of recess were included in the final analysis. The final sample of participants was randomly divided into a cut-point generation (22 participants, n = 11 girls) and a cross-validation (10 participants, n = 6 girls) group for analysis. Shapiro Wilk test was performed to assess distribution normality of decimal age, height, weight, BMI both in participants included and excluded from the study. Subsequently, either independent samples t-test or Mann-Whitney test were performed to assess differences in decimal age, height, weight and BMI between participants in the two groups based on normality distribution test. Differences in the distribution of boys and girls between participants included and excluded was assessed using Chi-square test.

This study proposed a novel approach to cut-point calculation divided in 3 phases comprising 1) initial ROC analysis, 2) the use of equivalence testing to identify the likely optimum cut-points at the group level and 3) cross validation of the cut-points.

Phase 1. During the first phase cut-points were calculated using ROC curve analysis in the cut-point generation group. R package pROC was used to perform ROC and calculate SB, MVPA and VPA cut-points. Consistent with previous studies, ROC analysis was initially performed including all the SB and PA levels (i.e. all recorded data across all activities). In contrast to previous research, and to reduce bias associated with unequal distributions of PA behaviours (Obuchowski and Bullen, 2018), ROC analysis was performed including pairs of activity levels, for example: SB versus LPA, MPA versus VPA (Table 6).

Table 6. Dichotomization of the data for the ROC analysis

Sedentary	
“1”	**“0”**
SB	LPA, MPA, VPA.
SB	LPA excluding standing while watching TV, MPA, VPA
SB	LPA
SB	LPA excluding standing while watching TV
Moderate physical activity	
“1”	**“0”**
MPA,VPA	SB, LPA
MPA,VPA	SB, LPA excluding standing watching TV
MPA	LPA
MPA	LPA excluding standing watching TV
Vigorous physical activity	
“1”	**“0”**
VPA	SB, LPA, MPA.
VPA	SB, LPA excluding standing watching TV, MPA
VPA	MPA

Scored “**1**” when the condition is present; Scored “**0**” when the condition is absent; **SB:** Sedentary behaviours; **LPA:** Light physical activity; **MPA:** Moderate physical activity; **VPA:** Vigorous physical activity.

To evaluate the effect of passive standing on the diagnostic accuracy of the cut-points, the acceleration signals collected during standing while watching TV were excluded from some of the conditions within ROC analysis (Table 6). The Youden index (i.e. selecting the acceleration threshold maximizing specificity [rate of true positives] and sensitivity [rate of true negatives]) and Distance method (i.e. selecting the point in the ROC curve that is closer to the left corner of the ROC curves plot) were used to calculate cut-points (Perkins and Schisterman, 2006). The Area Under the ROC curve (AUC) and the related confidence interval (ciAUC) were calculated as a measure of a test’s ability to discriminate between different conditions.

Sensitivity and specificity were calculated. Agreement between the criterion method (direct observation) and accelerometer estimates generated using the cut-points was assessed using % of agreement (%Ag) and Cohen's Kappa (CK). CK values were considered poor when lower than 0.00, slight when between 0.00 and 0.20, fair when between 0.21 and 0.40, moderate when between 0.41 and 0.60, substantial when between 0.61 and 0.80 and almost perfect when between 0.81 and 1.00 (Landis and Koch, 1977). Lastly, equivalency analysis was used to assess the group-level equivalence between the observation and cut-point derived SB and PA estimates (Dixon et al., 2018). Equivalency analysis compares an equivalence region derived from a criterion reference (e.g. observation) to the confidence interval for the difference in means between the criterion reference and a different method (e.g. accelerometery). The equivalence region is centred on the mean derived from the criterion reference while the confidence interval is centred on the mean obtained from the method to compare. Non-equivalence is rejected at the level α if 100(1-2α)% confidence interval for the difference in means lies entirely within the equivalence region. Based on previous research using equivalency testing to compare PA assessment methods, an equivalence region was used comprising ±10% the mean of the time spent in SB or PA activities assessed using the criterion method (observation) (DeShaw et al., 2018). Subsequently, the 90% confidence interval (as α was set at 0.05) for the difference in means between observed and cut-points derived time spent in SB and PA activities was calculated. Cut-point derived estimates were considered equivalent if the 90% confidence interval of the difference in means fell within the ±10% equivalence region.

Phase 2. Time spent in SB and PA levels derived from observation and ROC analysis generated cut-points were compared using equivalency. Subsequently, the most accurate cut-points were increased or decreased by 1mg progressively until cut-points providing the optimum estimates at the group-level (based on equivalency analysis) of SB, MVPA and VPA respectively were identified. Sensitivity, specificity, %Ag, and CK were re-examined for the revised cut-points and relative Bland Altman plots were produced (Martin Bland and Altman, 1986).

Phase 3. In the third phase, the revised cut-points developed in phase 2 were applied to the cross-validation group. In this phase agreement and accuracy were calculated for SB, LPA, MPA, MVPA and VPA. Sensitivity, specificity, %Ag, CK were calculated and equivalency analysis was performed. Additionally, Mean Absolute Percent Error (MAPE) was calculated as an individual-level measure of error and relative Bland Altman plots were produced.

Results

Forty-nine children (45% boys) agreed to take part in the study. Seventeen children did not complete the recess observation due to poor weather (heavy rain, icy conditions) and time constraints (data collection was restricted to December 2017). Thirty-two children (47% boys) completed all the assessments and were therefore included in the final analysis. The children who completed all the assessment included 12 children aged 5 years, 12 children aged 6 years and 8 children aged 7 years. Participant characteristics can be found in Table 7. No significant differences ($p > 0.05$) were found between participants included and excluded from the analysis in terms of gender, decimal age, height, weight and BMI.

Table 7. Participants' descriptive data

Initial group (n=49)				
	Boys (n=22)		**Girls (n=27)**	
	Mean	**SD**	**Mean**	**SD**
Decimal age (years)	6.5	0.8	6.5	0.7
Height (cm)	120.2	6.7	120.4	9.0
Weight (Kg)	23.6	3.9	24.4	6.1
BMI (Kg/m^2)	16.3	1.8	16.6	2.1
Final group (n=32)				
	Boys (n=15)		**Girls (n=17)**	
	Mean	**SD**	**Mean**	**SD**
Decimal age (years)	6.4	0.8	6.4	0.7
Height (cm)	119.4	6.3	120.2	9.5
Weight (Kg)	23.3	4.2	24.2	7.0
BMI (Kg/m^2)	16.2	2.0	16.5	2.5

Children were video recorded during recess for an average of 7 minutes and 17 seconds (range: 3 minutes and 35 seconds to 10 minutes and 11 seconds). Table 8 presents mean ENMO, standard deviation and number of observations for each activity children engaged in during the standardised activity protocol and recess.

Table 8. Accelerations observed in each sedentary behaviour and physical activity level recorded

				Non-dominant wrist		Dominant wrist		Hip	
Intensity (MET)	**Standardised Protocol**	**MET**	**Obs (s)**	**Mean (m*g*)**	**SD (m*g*)**	**Mean (m*g*)**	**SD (m*g*)**	**Mean (m*g*)**	**SD (m*g*)**
Sedentary	Lying while watching TV	1.2	18155	17	37	15	37	12	14
	Sitting while colouring	1.6	8640	20	47	37	65	11	13
	Sitting and playing with a tablet	1.4	8640	11	21	23	28	9	12
	Playing with LEGO	1.5	8640	52	48	51	47	11	12
Light	Standing	1.7	8640	20	39	12	27	9	13
Moderate	Walking briskly self-paced	4.6	2880	294	289	255	271	178	100
	Throw and catch	4.9	2790	444	370	432	374	83	88
Vigorous	Running	7.8	2865	1071	581	1115	601	607	179
	Obstacle course	7.2	2880	744	424	719	396	446	165
	Hopping	6.3	2563	844	552	762	491	452	241
	Recess								
Sedentary	Sitting down	1.4	51	64	64	67	80	18	27
Light	Standing	1.7	3007	103	165	117	210	45	88
	Walk slow	2.5	6164	204	249	207	266	120	128
Moderate	Walk brisk	4.6	665	528	397	473	398	336	196
	Jog slow	5.5	1364	652	459	644	537	434	259
	Dancing	3.6	13	654	557	347	340	162	126
	Ball games	6.0	23	773	337	652	379	379	189
	Jumping-jack	5.9	107	931	463	1081	449	281	247
Vigorous	Jog fast	6.8	1178	1103	632	1032	688	599	290
	Running	7.8	510	1772	894	1766	999	808	254
	Hopping	6.3	437	883	537	782	575	528	259
	Jump rope	6.9	577	801	390	1140	456	649	241
	Ball games	6.1	75	1663	696	1347	633	604	204

Obs: Number of observation of each behaviours where each observation corresponds to 1 second spent in the activity observed.
MET: Metabolic equivalent (1 MET equals the oxygen uptake of $3.5 mL \cdot Kg^{-1} \cdot min^{-1}$)

Phase 1

Cut-points calculated using the Youden and Distance methods are presented in Supplementary material 3 (see Supplementary material 3 Tables 1, 4 and 5). Most of the AUC were higher than 0.7 apart from "SB=1 and LPA=0" in the dominant wrist and hip placement with AUC equal to 0.611 and 0.689, respectively. The majority of cut-points presented higher sensitivity than specificity. Sensitivity ranged from 65.3% to 99.1% while specificity ranged from 61.8% to 96.5%. In terms of agreement, %Ag ranged from 71.5% to 95% while CK ranged from 0.43 to 0.82 representing moderate to substantial agreement.

Cut-points that included all the SB and PA levels in the ROC analysis generally presented higher AUC, higher sensitivity and lower specificity compared to the cut-points developed using pairs of activity levels. Moreover, the cut-points that included all SB and PA levels generally presented better agreement with observation for SB and lower agreement with observation for MVPA and VPA compared to cut-points developed using pairs of activity levels. Furthermore, excluding standing while watching TV from the ROC analysis resulted in an increase in AUC for SB and a decrease in the AUC for MPA and VPA ROC curves.

Based on the equivalency analysis (Figures 5-7) the cut-points developed using paired activity levels provided a better group-level estimate of time spent in SB, MVPA and VPA compared to cut-points developed using all the SB and PA levels (see CK and %Ag reported in Supplementary material 3: Supplementary Tables 1, 4 and 5). In general, Distance cut-points provided better estimates of SB, MVPA and VPA compared to Youden cut-points.

Phase 2

Results from phase 2 can be found in the Supplementary material 3 (Supplementary Tables 1-5). The cut-points providing the most comparable estimates of SB, MVPA and VPA were identified using equivalency testing (See Figures 3-5). Sensitivity, specificity, %Ag and

CK observed in phase 2 cut-points were either similar or higher compared to the those observed in phase 1 meaning that cut-points developed in phase 2 obtained higher agreement with the criterion reference for SB and PA. SB cut-points demonstrated lower %Ag and CK compared to the MVPA and VPA cut-points. Based on equivalency analysis, the amount of time spent in SB, MVPA and VPA calculated using phase 2 cut-points was equivalent on average at the group level to the observed values with the exception of the SB hip accelerometer cut-point. LPA and MPA displayed lower agreement with the observed values in comparison to other PA levels. Wider limits of agreement where observed in Bland Altman plots for hip SB and LPA cut-points compared to wrist cut-points (see Supplementary material 4: Supplementary Figures 1-6). Furthermore, a linear relation between bias and average of the differences was observed in Bland Altman plots of SB (Supplementary material 4: Supplementary Figures 1-3) as children engaged in approximatively the same amount of SB (23min).

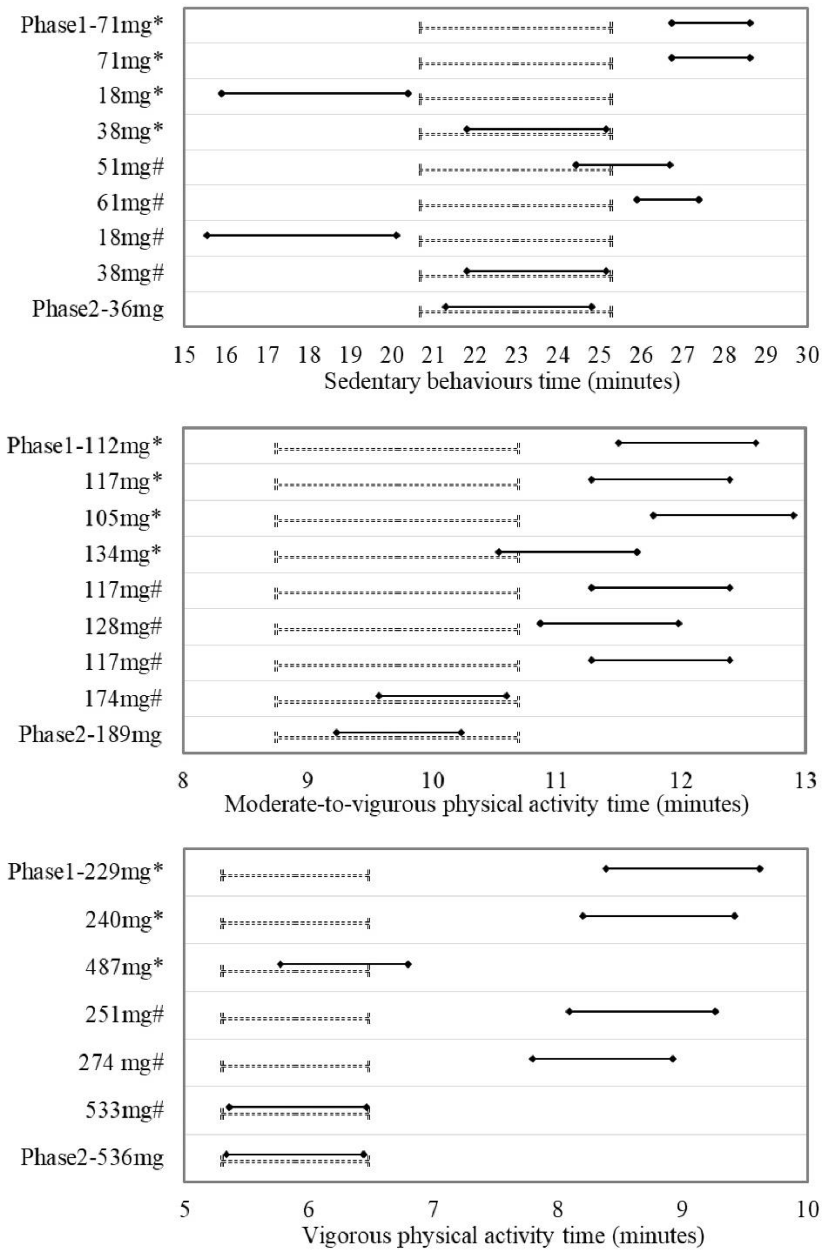

Figure 5. Non-dominant wrist equivalency analysis in cut-point generation group (Phase 1-2)

*: the cut-points marked with a * were calculated using ROC analysis Youden method.
#: the cut-points marked with a # were calculated using ROC analysis Distance method.
Phase 2: the cut-points in Phase 2 was calculated using equivalency analysis method.
Solid line: The solid line concerns the 90% confidence interval of the difference between observed and cut-point derived minutes spent in a specific activity level. The confidence interval is centred on the mean of the cut-point derived time estimate of the activity level taken into consideration (i.e. SB, MVPA, VPA).
Dashed line: The dashed line concerns the ±10% interval of the mean time estimate of a specific activity level calculated using observation. The ±10% interval is centred on the mean of the observation derived time estimate of the activity level taken into consideration (i.e. SB, MVPA, VPA).

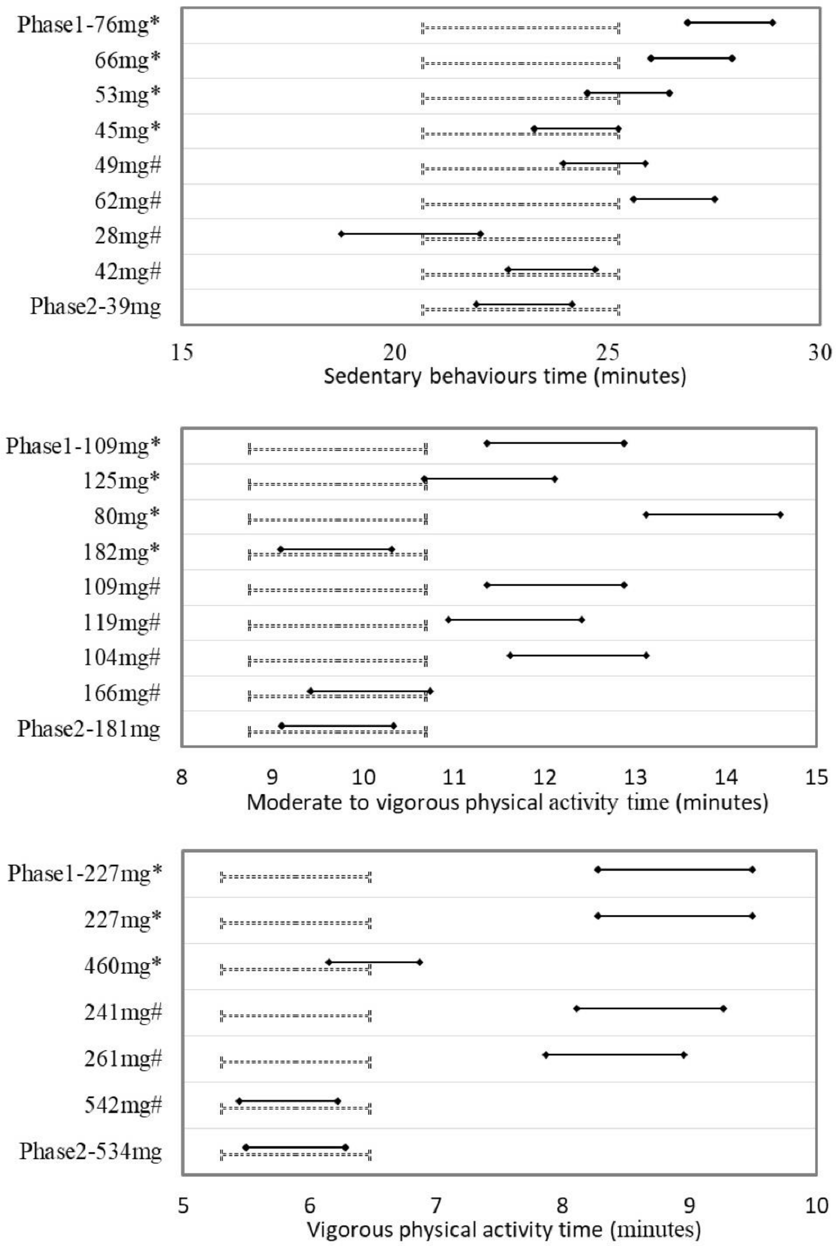

Figure 6. Dominant wrist equivalency analysis in cut-point generation group (Phase 1-2)

*: the cut-points marked with a * were calculated using ROC analysis Youden method.
#: the cut-points marked with a # were calculated using ROC analysis Distance method.
Phase 2: the cut-points in Phase 2 was calculated using equivalency analysis method.
Solid line: The solid line concerns the 90% confidence interval of the difference between observed and cut-point derived minutes spent in a specific activity level. The confidence interval is centred on the mean of the cut-point derived time estimate of the activity level taken into consideration (i.e. SB, MVPA, VPA).
Dashed line: The dashed line concerns the ±10% interval of the mean time estimate of a specific activity level calculated using observation. The ±10% interval is centred on the mean of the observation derived time estimate of the activity level taken into consideration (i.e. SB, MVPA, VPA).

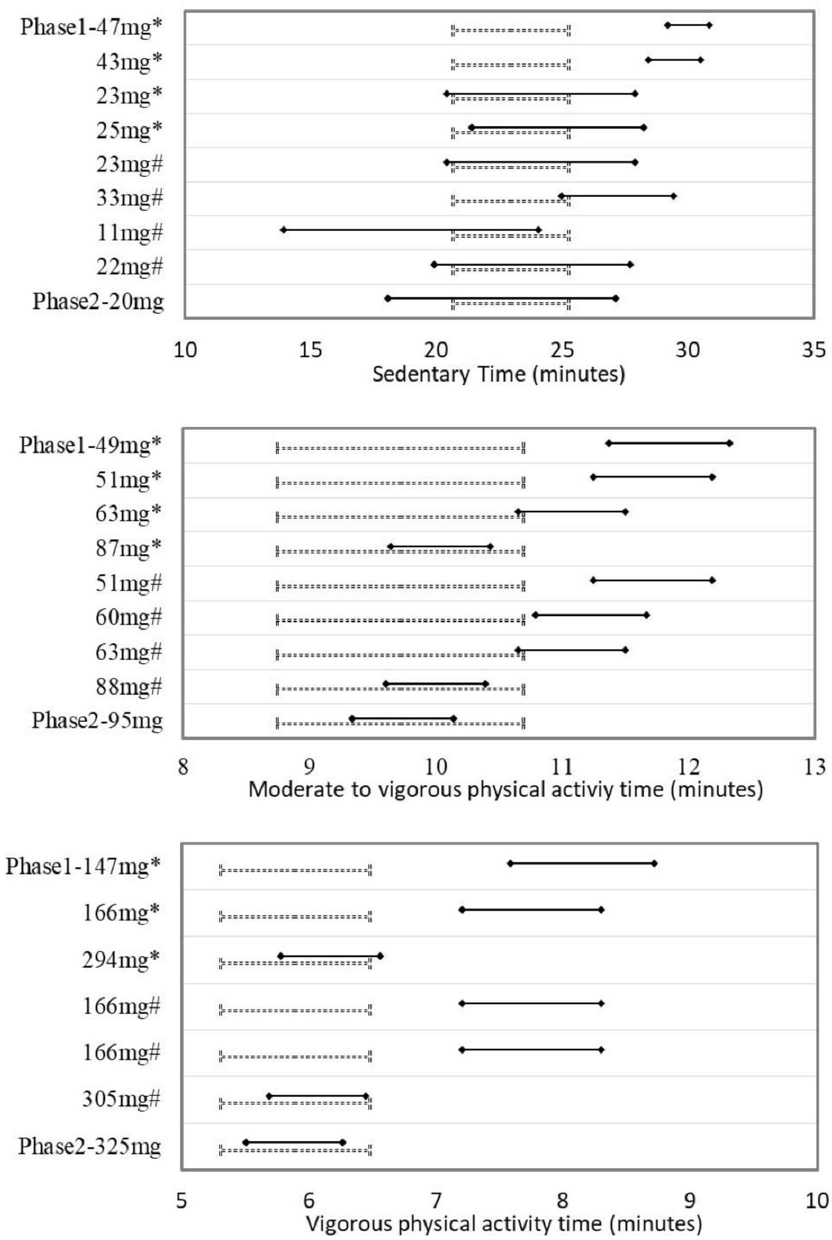

Figure 7. Hip equivalency analysis in cut-point generation group (Phase 1-2)

*: the cut-points marked with a * were calculated using ROC analysis Youden method.
#: the cut-points marked with a # were calculated using ROC analysis Distance method.
Phase 2: the cut-points in Phase 2 was calculated using equivalency analysis method.
Solid line: The solid line concerns the 90% confidence interval of the difference between observed and cut-point derived minutes spent in a specific activity level. The confidence interval is centred on the mean of the cut-point derived time estimate of the activity level taken into consideration (i.e. SB, MVPA, VPA).
Dashed line: The dashed line concerns the ±10% interval of the mean time estimate of a specific activity level calculated using observation. The ±10% interval is centred on the mean of the observation derived time estimate of the activity level taken into consideration (i.e. SB, MVPA, VPA).

Phase 3

The final cut-points developed in phase 2 were applied to the cross-validation group and the results are presented in Table 9.

Table 9. Cut-points performance in cross-validation group

							Equivalency analysis derived mean and confidence interval	
	Cut-point (m*g*)	**Sn (%)**	**Sp (%)**	**CK (a.u)**	**%Ag (%)**	**MAPE (%)**	**Obs (min)**	**Cut-point (min)**
Non-dominant wrist								
SB	<36	79.8	56.8	0.57	78.5	9.3	23.0±2.3	22.8±1.4
LPA	≥36&<189	38.4	81.9	0.20	72.5	19.6	9.1±0.9	9.5±1.2
MPA	≥189&<536	39.0	93.7	0.34	87.7	19.0	4.7±0.5	4.2±0.6
MVPA	≥189	82.6	78.0	0.78	92.0	9.0	10.2±1.0	10±0.8
VPA	≥536	75.1	68.7	0.69	92.7	12.9	5.5±0.6	5.9±0.5
Dominant wrist								
SB	<39	75.4	70.2	0.46	73.0	10.1	23.0±2.3	23.1±1.7
LPA	≥39&<181	27.4	78.4	0.06	67.5	18.7	9.1±0.9	9.6±1.2
MPA	≥181&<534	39.8	93.5	0.35	87.7	14.4	4.7±0.5	4.3±0.5
MVPA	≥181	79.1	76.0	0.76	91.4	13.5	10.2±1.0	9.5±1.0
VPA	≥534	67.6	95.6	0.64	92.0	16.2	5.5±0.6	5.3±0.7
Hip								
SB	<20	78.0	50.1	0.50	75.3	21.2	23.0±2.3	23.3±3.1
LPA	≥20&<95	30.0	80.2	0.10	69.4	51.9	9.1±0.9	9.3±3.0
MPA	≥95&<325	39.1	94.3	0.36	88.2	21.6	4.7±0.5	4±0.7
MVPA	≥95	79.3	75.6	0.76	91.2	13.2	10.2±1.0	9.7±1.0
VPA	≥325	78.2	96.1	0.73	93.8	11.3	5.5±0.6	5.7±0.4

SB: Sedentary behaviours; **LPA:** Light physical activity; **MPA:** Moderate physical activity; **MVPA:** moderate to vigorous physical activity; **VPA:** Vigorous physical activity; **Sn:** Sensitivity; **Sp:** Specificity; **CK:** Cohen's Kappa; **%Ag:** Percentage of agreement. **MAPE:** mean absolute percent error; **a.u.:** Arbitrary units; **Obs:** Concerns the mean time spent in SB and PA levels obtained by observation ±10% of the mean time spent in a specific activity level derived from observation; **Cut-point:** Concerns the mean of the cut-points derived SB and PA levels and the related 90% confidence interval of the difference between observed and cut-point derived minutes spent in a specific activity level.

Consistent with phase 2, SB cut-points demonstrated lower %Ag and CK compared to MVPA and VPA cut-points. LPA and MPA displayed lower agreement with the observed values in comparison to other PA levels with sensitivity between 27.4%-39.8%, specificity between 78.5%- 94.3%, %Ag between 67.5%- 87.7% and CK between 0.06-0.36. Based on the equivalency analysis, estimates were equivalent on average at the group level for SB, and MVPA for non-dominant wrist cut-points, and for SB for the dominant wrist cut-points. No estimates were considered equivalent for the hip placement. Non-dominant wrist placement showed slightly higher CK and %Ag together with lower MAPE and better results in equivalency analysis compared to hip placement in SB and LPA classification (Figure 8). Similarly, non-dominant wrist placement showed higher CK and %Ag compared to dominant wrist placement in SB and LPA classification. Wider limits of agreement were observed in Bland Altman plots for hip SB and LPA cut-points (Supplementary material 4: Supplementary Figures 16-21) compared to wrist cut-points confirming results from equivalency analysis and MAPE. In line with what observed in phase 2, a linear relation between bias and average of the differences was observed in Bland Altman plots of SB (Supplementary material 4: Supplementary Figures 16-18).

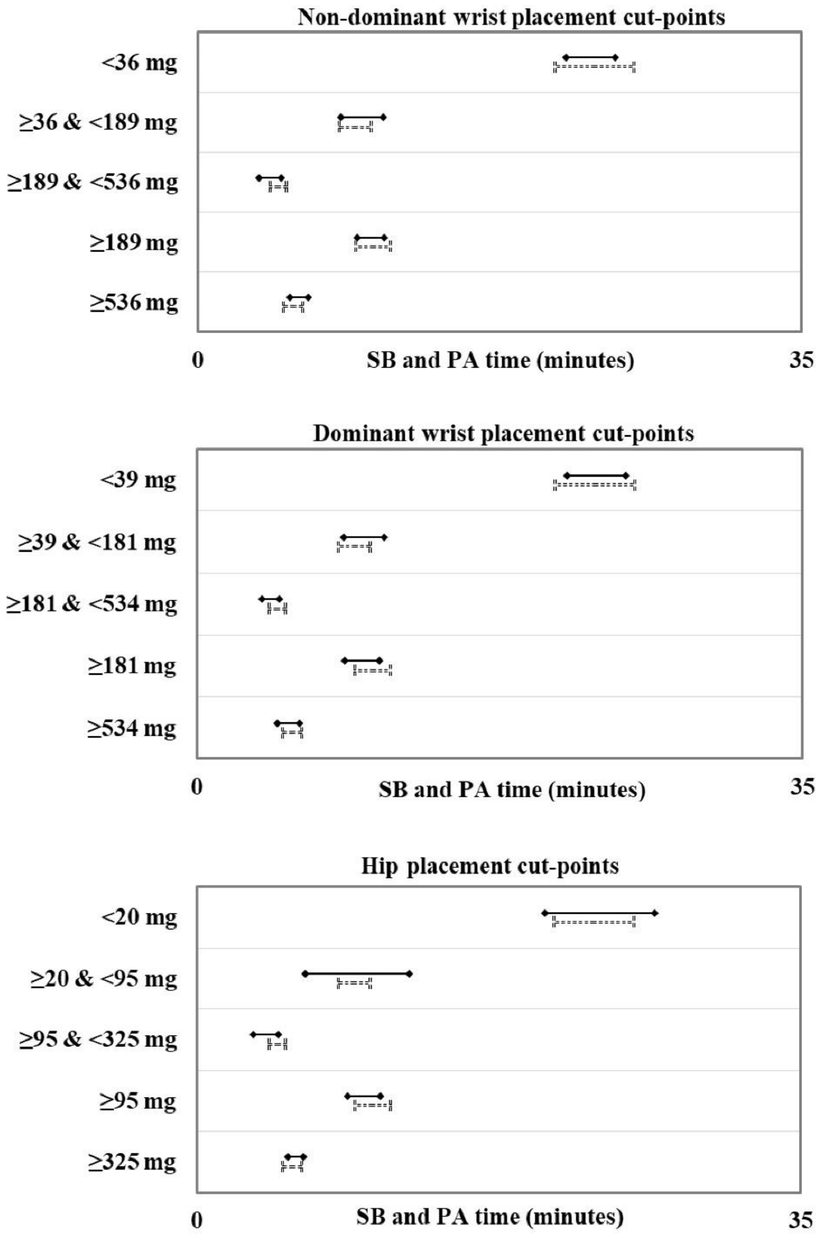

Figure 8. Standard confidence interval test in cross validation group (Phase 3)

SB: Sedentary behaviours; **LPA:** Light physical activity; **MPA:** Moderate physical activity; **MVPA:** moderate to vigorous physical activity; **VPA:** Vigorous physical activity.
Solid line: The solid line concerns the 90% confidence interval of the difference between observed and cut-point derived minutes spent in a specific activity level. The confidence interval is centred on the mean of the cut-point derived time estimate of the activity level taken into consideration (i.e. SB, LPA, MPA, MVPA, VPA).
Dashed line: The dashed line concerns the ±10% interval of the mean time estimate of a specific activity level calculated using observation. The ±10% interval is centred on the mean of the observation derived time estimate of the activity level taken into consideration (i.e. SB, LPA, MPA, MVPA, VPA).

Discussion

This study developed raw acceleration SB and PA cut-points in 5–7-year-old children for wrist and hip worn accelerometers. SB, MPA, MVPA and VPA cut-points demonstrated adequate levels of agreement (i.e. fair to substantial CK agreement, %Ag ≥ 73%) and error (MAPE ≤ 21.6%) with the criterion reference for all accelerometer placements. LPA measurement presented lower agreement with the criterion method compared to SB, MPA, MVPA and VPA, in line with findings observed in previous studies (Schaefer et al., 2014) with higher levels of error reported in hip placement (MAPE = 51.9%) compared to non-dominant (MAPE = 19.6%) and dominant placement (MAPE = 18.6%). However, the %Ag observed in this study in LPA classification was higher than the one observed in previous literature (Schaefer et al., 2014) suggesting that the cut-points are adequate for the use in the field. Non-dominant wrist cut-points performed slightly better than other placements in assessing SB and LPA behaviours presenting higher levels of %Ag and CK compared to both dominant wrist and hip placement together with lower levels of MAPE, better agreement in equivalency analysis and smaller confidence interval in Bland Altman plots compared to hip placements for SB and LPA. Not surprisingly, SB cut-points presented lower agreement with the criterion reference compared to MVPA and VPA cut-points confirming the known limitations of accelerometers when aiming to distinguish SB from passive standing LPA (Hildebrand et al., 2017). This study also demonstrated that combining equivalency analysis with ROC analysis could lead to more accurate cut-points than the ones derived from ROC analysis alone, based on the higher levels of agreement observed in Phase 2 compared to Phase 1 of the statistical analysis reported in this study.

Sedentary behaviours cut-points

SB cut-points were higher at the wrist than hip placement (36mg, 39mg and 20mg for non-dominant wrist, dominant wrist and hip placement respectively), in line with the majority of cut-points developed in previous literature (de Almeida Mendes et al., 2018). However, the opposite was reported by Hildebrand et al. (2017) who created SB cut-points for ActiGraph accelerometers using ENMO in a similar older age group (7-11 years old) (Hildebrand et al., 2017). Hildebrand et al. (2017) obtained higher cut-points for the hip placement compared to wrist placement (63.3mg and 35.6mg for hip and non-dominant wrist placement, respectively) (Hildebrand et al., 2017). Possible reasons behind this inconsistency in hip placement cut-points could be that Hildebrand et al. (2017) utilised different activities in their protocol, used the Youden method alone in the ROC analysis to identify cut-points, and involved a different criterion reference (i.e. activPAL) (Hildebrand et al., 2017).

Interestingly, higher sensitivity than specificity values were observed in Hildebrand et al. (2017) and in this study (Hildebrand et al., 2017). Hildebrand et al. (2017) argued that the lower levels of specificity might be due to the inclusion of standing as LPA in the study protocol (Hildebrand et al., 2017). Passive standing might lead to the absence of registered accelerations or low accelerations similar to SB activities. Despite being classified as LPA based on energy expenditure and/or the posture, standing watching TV does not necessarily involve movement and therefore could be classified as passive standing (Tremblay et al., 2017). Previous research has demonstrated the limitations of accelerometers in distinguishing stationary behaviours such as passive standing from SB (Ridgers et al., 2012; Aguilar-Farías et al., 2014). Another limitation of SB assessment using cut-points in is the lack of consideration of posture that is a key aspect of SB identification (Rowlands et al., 2016). This is confirmed by the results of this study where the mean acceleration during passive standing (Table 8) was below the SB cut-points.

SB raw acceleration cut-points have been developed by Schaefer et al. (2014) and Duncan et al. (2016) in GENEActiv devices for children aged between 5-7, though, rather than using ENMO these studies utilised different metrics to represent acceleration signals (Schaefer et al., 2014; Duncan et al., 2016). SB cut-point presented in both Schaefer et al. (2014) and Duncan et al. (2016) studies were higher than SB cut-points developed in this study (36mg, 39mg, 20mg) with values of 190mg and 75mg (converted from time to independent unit mg) respectively (Schaefer et al., 2014; Duncan et al., 2016). This is in line with previous studies where higher accelerations were observed in GENEActiv compared to ActiGraph when measuring the same participants simultaneously (Rowlands et al., 2018b). However, key reasons for the disparity in cut-points is likely due to the different metrics that have been used to represent the acceleration meaning cut-points are not directly comparable (de Almeida Mendes et al., 2018).

Light, Moderate and vigorous physical activity cut-points

Hildebrand et al. (2014) developed MVPA and VPA cut-points for ActiGraph using ENMO in 7-11 year old children (Hildebrand et al., 2014). Their reported cut-points were higher for both wrist (MVPA: 201.4mg, VPA: 707.0mg) and hip (MVPA: 142.6mg, VPA: 464.6mg) placements compared to the ones in this study (MVPA: 189mg for non-dominant wrist, 181mg for dominant wrist and 95mg for hip; VPA: 536mg for non-dominant wrist, 534mg for dominant wrist and 325mg for hip) (Table 9) (Hildebrand et al., 2014). There are several potential reasons for the differences between the Hildebrand cut-points and the ones reported in the present study. For example, the difference in age range between the participants involved, the use of indirect calorimetry as criterion reference rather than observation, using linear regression for cut-points identification and the use of different activities within the study protocol (Hildebrand et al., 2014). Van Loo et al. (2018) assessed the accuracy of three sets of

MVPA and VPA raw accelerometers cut-points developed by Hildebrand et al. (2014) Philips et al. (2013) and Schaefer et al. (2014) for GENEActiv wrist mounted devices in 5-8 year old children and found that these cut-points led to considerable misclassification of PA levels (Phillips et al., 2013; Hildebrand et al., 2014; Schaefer et al., 2014; Van Loo et al., 2018). Interestingly, none of the cut-points examined by van Loo et al. (2018) were originally developed from a sample of 5-8 years old children and therefore it is possible that they were not adequate for the classification of MPA, MVPA and VPA in that age group (Phillips et al., 2013; Hildebrand et al., 2014; Schaefer et al., 2014; Van Loo et al., 2018).

When considering previous studies that examined raw acceleration cut-points in 5-7 year old children, only Schaefer et al. (2014), Hildebrand et al. (2014) and Van Loo et al. (2018) reported %Ag (Hildebrand et al., 2014; Schaefer et al., 2014; Van Loo et al., 2018). Schaefer et al. (2014) reported slightly higher %Ag for the SB cut-point (83.3%) but lower %Ag for LPA (29.4%), MPA (41%) and VPA (88.7%) compared to this study (%Ag in this study: SB between 73% and 78.5%, LPA between 67.5% and 62.5%, MPA between 88.7% and 88.2%, VPA between 92% and 93.8%) (Schaefer et al., 2014). Similarly, Hildebrand et al. (2014) and Van Loo et al. (2018) obtained lower %Ag for MPA and VPA (%Ag for Hildebrand et. (2014): MPA between 33% and 55%, VPA between 68% and 80%; %Ag for Val Loo et al. (40): MPA between 45.4% and 52%, VPA between 70% and 93.6%) (Hildebrand et al., 2014; Van Loo et al., 2018). In this study according to Cohen’s Kappa values, LPA estimates demonstrated slight agreement, while MPA estimates showed fair agreement, and SB, MVPA and VPA moderate to substantial agreement. Given that no previous calibration studies in this age group have reported CK, future studies should include this measure of reliability to account for chance agreements. Overall, the %Ag reported in this study is higher than those observed in previous studies applying raw acceleration cut-points in 5-7-year-old children, demonstrating that the cut-points proposed in this study could lead to improved accuracy in PA assessment.

Strengths and limitations

A major strength of this calibration study was its high ecological validity as the protocol included direct observation of children's SB and PA during recess within the school playground and during a standardised protocol of activities performed in their PE hall. Additionally, this is the first accelerometer calibration study in this age group to consider different methods of cut-point calculation, including: i) exploring the use of paired activity levels in ROC curve analysis, ii) examining the Youden and distance methods for cut-point development, and iii) using equivalency methods to identify and refine cut-points. Further strengths are the use of the ENMO metric, emerging as the most frequently used metric to process raw acceleration and generate thresholds for multiple accelerometer placements (Welk, 2019).

Despite the advantages of using direct observation as criterion reference for SB and PA assessment exposed in the methods section, it should be acknowledged that direct observation is not the gold standard for the measurements of energy expenditure and presents a level of subjectivity. Furthermore, because of time constraints and participants' availability, it was not possible for the all the initial 49 participants to complete the study protocol and to obtain a balanced number of children within each age group involved in the study (12 children aged 5 years, 12 children aged 6 years, and 8 children aged 7 years). It was recognised that the limited number of children in the cut-point generation group together with the use of statistical analysis methods maximizing accuracy might lead to over fitting related problems. However, the final sample of 32 participants within this study is similar to the sample sizes reported in previous accelerometer calibration studies in children where the number participants ranged between 21 and 49 (Evenson et al., 2008; Beets et al., 2011; Mackintosh et al., 2012; Phillips et al., 2013; Hänggi et al., 2013; Schaefer et al., 2014; Hildebrand et al., 2014, 2017; Kim et al., 2014; Johansson et al., 2015, 2016; Chandler et al., 2016; Roscoe et al., 2017).

Future directions

For future calibration studies, researchers should involve an equal number of participants in each age group to guarantee that each age is equally represented in the sample, together with a bigger sample size to guarantee a better representation of the population. In line with previous research, difficulties were encountered in the selection of standardised LPA activities for the testing protocol. Similar to previous studies (Hildebrand et al., 2017; Van Loo et al., 2017, 2018), this study classified slow walking and standing as LPA. Given that passive standing might lead to misclassification of SB and LPA, other activities that are representative of 5-7 years old children free-living LPA should be identified in the future. Moreover, future studies should examine methods to integrate postural aspects to the measurement to account for accelerometers limitations in classifying sedentary behaviours.

Conclusion

SB, LPA, MPA, MVPA and VPA cut-points demonstrated adequate accuracy in all accelerometer placements. Non-dominant accelerometer placement presented slightly better agreement with the criterion reference compared to the dominant wrist and hip placements for SB and LPA. However, no other differences were highlighted between the accelerometer placements. These findings can be used to inform the decisions made by researchers in relation to the assessment of young children's PA and SB. Furthermore, the study protocol, methods and analysis can inform the development of more rigorous calibration studies and subsequent analyses to determine cut-points in the future. Results obtained in this study suggest that cut-points developed using Youden method involving all SB and PA levels in ROC analysis can lead to large misclassification of SB and PA levels. Future researchers should include paired activity levels analysis together with distance method in ROC analysis in combination with equivalency analysis and Cohen's Kappa statistic to select the most accurate SB and PA cut-points.

Chapter 4: Study 2

Validation of modified SOFIT+: relating physical activity promoting practices in physical education to moderate-to-vigorous physical activity in 5–6-year-old children

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Thesis studies map: Chapter 4

Stydy	Objectives / Main outcomes
Study 1: Development of raw acceleration cut-points for wrist and hip accelerometers to assess sedentary behaviour and physical activity in 5-7 year old children	*Main outcomes:* • The raw acceleration cut-points developed for GT9X ActiGraph devices presented acceptable validity and reliability for hip, dominant wrist and nondominant hip placement to assess SB, LPA, MPA and VPA in 5–7-year-old children. • Different accelerometer wear position - hip, dominant wrist or nondominant wrist – offer similar accuracy in estimating PA/SB.
Study 2: Validation of modified SOFIT+: relating physical activity promoting practices in physical education to moderate-to-vigorous physical activity in 5–6 year old children.	*Objective:* • To assess validity and reliability of a modified version of the System for Observing Fitness Instruction Time to Measure Teacher Competencies Related to Physical Activity Promotion (SOFIT+).
Study 3: Teacher physical activity promoting practices and children's physical activity within physical education lessons underpinned by motor learning theory (SAMPLE-PE)	*Objectives:* • To assess children's MVPA in PE within Linear Pedagogy and Nonlinear pedagogy and to compare this to current practice within PE delivery in primary schools. • To assess teaching practices associated with PA in PE within Linear Pedagogy and Nonlinear pedagogy and to compare this to current practice within PE delivery in primary schools.
Study 4: Effect of Linear and Nonlinear pedagogy physical education interventions on children's physical activity: a cluster randomized controlled trial (SAMPLE-PE)	*Objective:* • To evaluate the effect of PE interventions guided by Linear pedagogy and Nonlinear pedagogy on habitual PA over the whole week and different segments of the week compared to the control group (current practice in PE) in 5–6-year-old children.

Thesis context

The validation of a modified version of the SOFIT+ was completed in this study as the assessment of teaching practices associated with MVPA in PE was needed in study 3 (chapter 5). Furthermore, in this study, the non-dominant wrist cut-points developed in study 1 (chapter 3) were used in this study to measure children's MVPA during PE.

Introduction

Across the globe, a significant proportion of children do not meet physical activity (PA) guidelines which advise that children should engage in at least 60 minutes of moderate-to-vigorous PA (MVPA) every day (Janssen and LeBlanc, 2010; Roman-Viñas et al., 2016; Manyanga et al., 2019; Tanaka et al., 2020). This is a concern as low levels of MVPA during childhood are associated with increased likelihood of obesity, metabolic syndrome, poor mental health and lower quality of life (Biddle and Asare, 2011; Poitras et al., 2016; Wu et al., 2017; Whooten et al., 2019). Furthermore, low levels of MVPA in childhood tracks into adolescence and adulthood (Telama et al., 2014). School is an important setting for MVPA promotion as children spend a significant proportion of their time there. Furthermore, for many children it is the only place where they can participate in organised PA (Chen and Gu, 2018), such as Physical Education (PE) (Hills et al., 2015).

The National Curriculum for PE in England states that primary school children should develop movement competencies enabling them to participate in a wide range of physical activities and that children should be taught to master fundamental movement skills, to participate in sport games and perform simple dance movements (UK Department of Education, 2013). Furthermore, the UK Government recently published a plan reporting actions and funds to support the delivery of high quality PE and PA promotion in schools (UK Department of Education, 2019). International guidelines suggest that children should engage in MVPA for at least 50% of their PE lesson (Pate et al., 2006), whilst also learning movement skills and knowledge about health and fitness that will support PA beyond PE (Hills et al., 2015). PE teachers therefore have a responsibility to support MVPA promotion during lessons (McKenzie et al., 2000; Rutten et al., 2012). Previous research has shown that different teaching practices during PE are positively (e.g. engaging children in game play, proposing partner activities, teacher engaging in PA with children) or negatively (e.g. instructing children, proposing activities requiring waiting time, proposing activities including elimination from the game) associated with children's and adolescent's MVPA levels during lessons (McKenzie et al., 1992; Weaver et al., 2016; Fairclough et al., 2018). Better understanding of teaching practices is important to help both researchers and practitioners enhance MVPA promotion in PE (Castelli et al., 2013). For this reason, it is important to develop valid and reliable observation tools to assess key aspects of teaching practices that might affect children's MVPA. Furthermore, such tools could be used for process evaluation assessment purposes for academics interested in enhancing MVPA within PE and coaching contexts (Stylianou et al., 2016).

The modified System for Observing Fitness Instruction Time (SOFIT+) is a modified version of the SOFIT systematic observation tool (McKenzie et al., 1992) to assess teaching practices associated with MVPA. SOFIT+ was designed by Weaver et al. (2016) with the aim of providing a more comprehensive assessment of the teaching practices associated with children's MVPA during PE or coaching sessions. Within SOFIT+, *Lesson Context* variables (e.g. how lesson content was delivered) were kept as in the original SOFIT observation tool while new variables were added to assess *Activity Context* (e.g. how activities were structured), *Teaching Behaviours* (e.g. what the teacher was doing during) and teacher *Activity Management* (e.g. what management strategies where used by the teacher). SOFIT+ has been previously validated in elementary school children from the USA and high school students from the UK (Weaver et al., 2016; Fairclough et al., 2018). To account for gender specific differences in MVPA engagement during PE or coaching (i.e. boys being more active than girls) and gender specific attitudes towards different physical activities (Tanaka et al., 2018; Peral-Suárez et al., 2020), previous validation studies evaluated the relation between teacher practices and MVPA engagement in boys and girls separately (Weaver et al., 2016; Fairclough et al., 2018). However, SOFIT+ has not been validated in children younger than 6-years-old and amongst primary school children from countries outside USA, limiting the cross-cultural validity of the tool (Weaver et al., 2016; Fairclough et al., 2018). Furthermore, SOFIT+ was developed to assess teaching practices in line with traditional teacher-centred educational approaches (Weaver et al., 2016). In a traditional PE approach, children have low or no autonomy during lessons and are normally engaged in progressive drills in order to master movement techniques proposed by the teacher (Rudd et al., 2020a). Contemporary, child-centred approaches to PE include production teaching styles (i.e. Guided Discovery, Problem-solving, Individual-based choice, Learner initiated, Self-teaching) (Mosston and Ashworth, 2008) and teaching approaches based on Nonlinear pedagogy (Chow et al., 2011) that are not yet investigated in SOFIT+. In Nonlinear pedagogy, the role of physical educators is to design learning experiences using a set of constraints which can channel learners' movement skill development while learners have higher levels of autonomy and are free to experiment and find movement solutions that best answer their individual needs (Chow & Atencio, 2014; Rudd et al., 2020). Nonlinear pedagogy fosters higher motivation toward participation in PE compared to traditional approaches and therefore is considered a promising strategy for PA promotion (Moy et al., 2016). A typical characteristic of PE lessons with child-centred approaches is for the teacher to engage in one-to-one or small group interaction with children to help them in their personal and unique learning process (Mercier, 1993). Thus, it is important to assess how these Nonlinear and child-centred teaching practices might be associated with MVPA participation. Furthermore, previously validated SOFIT+ tools (Weaver et al., 2016; Fairclough et al., 2018) did not assess the association between management practices during PE lessons and MVPA (i.e. *Signalling*, *Retrieving equipment from multiple access points*, *Retrieving equipment from one access point*, *Interruption Public*, *Interruption Private*). Therefore, the examination of how management practices might promote or hinder MVPA participation in children requires investigation.

The present study therefore aimed to (i) validate the SOFIT+ tool for use in 5-6 years old children within a UK population, (ii) to revise the SOFIT+ tool to integrate aspects of child-centred teaching practices that might be associated with MVPA and (iii) to evaluate the association between management practices in PE with children's MVPA.

It was expected that teaching practices would be associated with Children's MVPA in line with the previous SOFIT+ validation study in this age group (Weaver et al., 2016) while it was expected that teacher-centred teaching practices and management teaching practices would be related with children's MVPA during PE.

Methods

Modified System for Observing Fitness Instruction Time SOFIT+

SOFIT+ was designed to measure teacher practices that promote or restrict children's participation in MVPA during PE lessons (Weaver et al., 2016). The teaching practice variables within SOFIT+ are divided into 4 categories including *Lesson Context* (e.g. how the content of a lesson was delivered), *Activity Context* (e.g. how activities were structured), *Teacher Behaviours* (e.g. what the teacher was doing) and *Activity Management* (e.g. what management strategies were used by the teacher) (for full description, see Supplementary material 5). Teaching practices in the above categories are systematically observed through the SOFIT+ observation tool. The observation protocol consists in a partial interval recording observation tactic using an observe and record format divided into 2 phases where phase 1 concerns *Lesson Context* and *Activity Context* assessment, while phase 2 concerns *Teacher Behaviours* and *Activity Management* assessment. Each observation phase lasts 20 s, divided into 10 s of observation and 10 s of coding for a total duration of 40 s per scan. When recording the teaching practices, a decision is made regarding whether one or more of the predetermined teaching practices occurred during the 10 s observation intervals. However, only the *Lesson Context* variable that is observed for the longest duration and involving the majority of individuals over the 10 s observation should be recorded (i.e. only one *Lesson Context* variable per 10 s observation should be recorded). Similarly, only one *Activity Context* variable (i.e. the one observed for the longest duration and including the majority of individuals) should be recorded between *Individual Activity*, *Partner activity*, *Small sided activity*, *Large Sided Activity* and *Whole Class Activity* for each 10 s observation. Lastly, only one *Teacher Behaviour* should be recorded between *Supervises*, *Instructs Single Child*, *Instructs Group*, *Instructs Class*, *PA Engaged* and *Off-task* for each 10 s observation.

For the purposes of this validation study, small modifications were made to the SOFIT+ in order to include contemporary PE teaching practices identified by the research team. A variable called '*Discovery Practice*' was added to the category *Lesson Context* to code time where children were invited by the teacher to explore different movement solutions creatively to meet a task or solve a movement challenge. The inclusion of the '*Discovery Practice*' variable was made to recognise "production" teaching styles (Mosston and Ashworth, 2008) and Nonlinear Pedagogy approaches (Chow et al., 2011), which have been proposed to foster motivation towards engagement in PA (Zarazaga Raposo et al., 2020). *Discovery Practice* is distinguishable from *Skill Practice* as children are given higher levels of autonomy over their movement task and the instructor/teacher does not necessarily explain or demonstrate specific movements required in the task (Mosston and Ashworth, 2008; Chow and Atencio, 2014). Furthermore, *Discovery Practice* can be distinguished from *Game Play* as it does not necessarily involve games and the main focus of the activity is exploring different ways of moving or solving movement problems (Mosston and Ashworth, 2008). A variable called '*Large Sided Activity*' was added to the *Activity Context* category to code activities where children were divided in groups of 5 or more as this type of grouping is typical of team invasion games and could be associated with different levels of engagement compared to activities presenting smaller grouping or whole class activities (Tanaka et al., 2018). '*Supervises*' was added within *Teacher Behaviours* to code for moments where the teacher observes students without interacting with them, as this was not included in previous versions of SOFIT+. Finally, the category 'Instruction' within the *Teacher Behaviours* category, was divided into three sub-categories comprising: '*Instructs Single Child*', '*Instructs Group*' and '*Instructs Class*'. This modification was proposed as the interaction between the teacher and an individual or a small group can present a different function compared to instructing the whole class and it is typically associated with times where the class is engaged in *Motor Content* activities (Dale, 1991; Nicaise et al., 2007). Therefore, instructing a single child or a small group could be associated with higher MVPA engagement compared to instructing a whole class, as the children who are not involved in the instruction could be left free to engage in MVPA promoting activities.

Design, participants and settings

This study was conducted as part of the SAMPLE-PE intervention cluster randomised controlled trial (Rudd et al., 2020a). The study protocols and procedures were approved by the institutional research ethics committee (Reference 17/SPS/031). Gatekeeper consent was obtained from head teachers at 12 primary schools in North-West of England and informed parental consent and child assent was collected for 360 5-6-year-old children within year 1 classes in each primary school for the cluster randomised controlled trial. Due to time constraints and feasibility issues, a convenience sample of nine schools and a random selection of 50% of children in each class were invited to participate in this study. Nine teachers/coaches provided consent to be observed using SOFIT+ and to be video recorded while delivering PE lessons.

Procedures

Data collection occurred during PE lessons delivered within the SAMPLE-PE cluster randomised controlled trial between February and June 2018 (Rudd et al., 2020a). The year 1 classes participating in this study were 15 in total. Three PE lessons were randomly selected for data collection in each year 1 class over a period of 15 weeks (1 PE lesson was selected every 5 weeks in each class). Therefore, 45 PE lessons in total were scheduled to be assessed. During the data collection period, children from 6 schools (intervention group comprising 10 classes) received a PE intervention led by trained sport coaches (external providers) while children in the remaining 3 schools (control group comprising 5 classes) maintained their usual PE delivery practice (Rudd et al., 2020a).

Before the start of each lesson observation, researchers randomly selected 50% of the children participating in the research study and fitted an ActiGraph GT9X accelerometer on their non-dominant wrist to capture MVPA levels during PE. If a child was absent or could not participate in PE another randomly selected child was invited to wear an accelerometer. PE lesson start time was recorded by a researcher. The children then participated in their PE lessons, which were video recorded using GoPro Hero 5 video cameras (GoPro, USA), positioned to cover the full teaching area. The PE teachers/coaches wore a microphone during the PE lesson to capture audio recordings of their verbal delivery. The time that the PE lesson ended was recorded and children subsequently returned their accelerometers to the researchers. The digital video and audio recordings of the PE lessons were saved to University servers for later analysis by trained researchers using SOFIT+.

Anthropometrics

Body mass was assessed to the nearest 0.1 kg using scales (model 760, Seca, Hamburg, Germany) while stature was assessed using stadiometers to the nearest 0.1 cm (The Leicester

Height Measure, Child Growth Foundation, Leicester, United Kingdom) (Dettwyler, 1993). All anthropometric measurements were taken twice while a third measurement was taken in case the first two measurements differed by more than 1% and subsequently the mean between the measurements was taken. Body mass index (BMI) was calculated using stature and mass measurement.

Demographics

Children's demographic data (i.e. date of birth, gender, ethnicity, household postcode) were collected using questionnaires that parents filled and returned together with the consent form. Children's neighbourhood deprivation rank and decile were calculated from household postcode using the English indices of deprivation (UK Government Ministry of Housing Communities & Local, 2018).

Physical activity assessment

The accelerometers GT9X ActiGraph were set to record at 100 Hz over 1 second epochs to measure acceleration in a range of ±8 g on x, y and z axes. The acceleration data were downloaded using ActiLife software (ActiGraph, USA) in 1 s epochs and then exported to .csv format. GGIR package (Van Hees, 2020) from R software version 3.2.5 was then used to extract Euclidean Norm Minus One (ENMO) acceleration from csv. files and to classify time spent in MVPA using age appropriate validated cut-points (Crotti et al., 2020).

Observer training and reliability

Three trained researchers (including me, the author of this PhD thesis) performed all coding of SOFIT+ observations from the video-recordings. As a part of the training process the researchers read the SOFIT+ manual, familiarised themselves with the instrument based on methods reported in Weaver et al. (2016) SOFIT+ validation study, discussed and clarified any doubts concerning the SOFIT+ variables, committed this information to memory, and then independently analysed SOFIT+ training videos of PE lessons not collected as part of this study. After analysing each video and before analysing a new one, the researchers discussed and resolved any discrepancies between their coding. In line with previous research (Ridgers et al., 2010), the researchers' training was considered completed once inter-rater agreement reached >80% in each category over 3 consecutive video-recorded lessons. A total of nine PE lesson videos were analysed before reaching the established reliability target.

Once the training was completed, the lead author (represented by me, the author of this PhD thesis) analysed all the video-recorded PE lessons collected in this study (n=45) while the other two trained researchers independently analysed 7 randomly selected lessons each for a total of 14 lessons. Subsequently, inter-rater reliability was evaluated between the lead author and the other trained researchers over the 14 randomly selected lessons, corresponding to more than 30% of the lessons collected within this study consistently with previous validation of observation tools (Weaver et al., 2014; Fairclough et al., 2018).

SOFIT+ validity

To assess SOFIT+ construct validity, this study evaluated if SOFIT+ variables were associated with children's MVPA, as measured by accelerometry, in the hypothesized directions in line with previous SOFIT+ validation studies (Weaver et al., 2016; Fairclough et al., 2018) also reported in Supplementary material 5. Two methods were used to assess construct validity. The first method concerned the association between a SOFIT+ index and children's MVPA, while the second method concerned the association between each SOFIT+ variable and children's MVPA. The SOFIT+ index was designed to account for the complex nature of PE lessons where both MVPA promoting and MVPA decreasing teaching practices could be observed simultaneously (e.g. a teacher is verbally encouraging PA during an activity that includes waiting and elimination) in line with the idea of teaching practices simultaneity in the classroom (Doyle, 2015). To create the SOFIT+ index, the presence of a MVPA promoting teaching behaviour within one of the four categories (i.e. *Lesson Context*, *Activity Context*, *Teacher Behaviours* and *Activity Management*) was coded as 1 point. Similarly, the absence of any MVPA decreasing teaching practices within these categories of the SOFIT+ was coded as 1 point accordingly with what reported by previous SOFIT+ validation studies (Weaver et al., 2016; Fairclough et al., 2018). Therefore, the SOFIT+ index could range from 0 to 9 within a complete scan (lasting 40 s).

Statistical analysis

R software version 3.2.5 (R Foundation, www.r-project.org) was used to complete the data analysis and the descriptive statistics calculation. Inter-rater reliability was calculated using percentage of Agreement and Cohen's Kappa, that was defined as poor when lower than 0.00, slight when between 0.00 and 0.20, fair when between 0.21 and 0.40, moderate when between 0.41 and 0.60, substantial when between 0.61 and 0.80 and almost perfect when between 0.81 and 1.00 (Landis and Koch, 1977). To examine construct validity, MVPA levels were classified using age appropriate cut-points on a second by second basis (Crotti et al., 2020). SOFIT+ teaching practices observations and PA recordings from accelerometers could be matched as researchers reported the start time of each PE lesson while accelerometers recorded time together with acceleration second by second. In other words, each 40 s of PA measurement for each child was matched to a time specific SOFIT+ scan within the lesson the children participated in. A MVPA variable representing the number of seconds spent in MVPA within each 40 s of SOFIT+ scan was created and stratified into four categories: 0 to 9 s of MVPA, 10 to 19 s of MVPA, 20 to 29 s of MVPA, and 30 to 40 s and of MVPA. The likelihood of the SOFIT+ index score to predict time spent in 10 to 19 s, 20 to 29 s or more than 30 s of MVPA compared to the reference category of 0 to 9 s of MVPA was estimated using multinomial regression analysis. Multinomial regression models were also used to asses if individual SOFIT+ variables were associated with time spent in 10 to 19 s, 20 to 39 s or more than 30 s of MVPA compared to 0 to 9 s of MVPA. To account for different teaching practices being recorded within the same SOFIT+ scan, multiple SOFIT+ variables within two models were fitted. A multinomial model was designed to evaluate if *Lesson Context*, *Teacher Behaviours* and *Activity Management* variables were associated with MVPA in children within all SOFIT+ observations. Furthermore, a separate multinomial model was employed to evaluate the association between *Activity Context* variables and MVPA excluding observations where *Knowledge* and *Management* were recorded, as *Activity Context* variables can only be observed during *Motor Content* activities (i.e. *Skill Practice*, *Game Play*, *Free Play*, *Fitness* and *Discovery Practice*). Furthermore, groups of mutually exclusive teaching practices within the same category (e.g. *Skill Practice*, *Game Play*, *Fitness* and *Discovery Practice*) were transformed into dummy variables to be fitted in the models. The analysis for boys and girls was done separately as gender differences were found in children MVPA engagement within PE (Tanaka et al., 2018) and in view of gender specific attitudes towards different physical activities that could affect children's MVPA engagement with girls generally preferring individual sports and activities with and artistic orientation (e.g. dance, gymnastic) and boys preferring team invasion activities and activities with a predominant component of competitiveness (e.g. football, racket sports) (Peral-Suárez et al., 2020).

Results

Audio was not recorded in one of the PE lessons because of technical problems, therefore a total of 44 PE lesson observations were used for analysis. The final sample included 162 children (86 girls) comprising 52.0% of White British children, 2.7% White other nationality, 12.7% Black, 16.0% Asian, 17.3% of other ethnicities and 64.8% of children from the most deprived deprivation decile. Boys presented a mean age of 6.0 (SD = 0.3) years and a mean BMI equal to 16.0 kg/m^2 (1.8 kg/m^2) while girls presented a mean age of 5.9 (0.3) years and a mean BMI equal to 16.6 kg/m^2 (1.9 kg/m^2). Due to children being absent from school, not participating in PE or technical issues, 114 (56 girls) participants were assessed over 3 lessons, 32 (24 girls) participants were assessed over 2 lessons and 16 (6 girls) participants were assessed in 1 lesson. The lessons lasted on average 32:07 min:s (06:14 min:s) and 14 (31.8%) of them took place outdoors. Children spent on average 34.8% (11.3%) of the lessons engaged in MVPA. The main PE contents of the lessons were ball games (4), dance (10), gymnastic (10), object control (11), relays/obstacle courses (5) and tag games (4).

Results for inter-rater reliability concerning SOFIT+ training can be found in supplementary material 5 with an average percentage of agreement of 95.8% comprised between 82.2% and 99.7% and average a Cohen's Kappa equal to 0.76 comprised between 0.25 and 0.98 meaning that reliability was fair to almost perfect. The Inter-rater reliability concerning the data collected in this study can also be found in supplementary material 5 and involves an average percentage of agreement equal to 95.3% comprised between 88.8% and 99.7% and an average Cohen's Kappa equal to 0.70 comprised between 0.25 and 0.97 meaning that the reliability was from fair to almost perfect.

A total of 2067 SOFIT+ scans were completed (Table 10) with a number of SOFIT+ scans per lesson ranging from 19 to 69. Variables including '*Free Play*' (*Lesson Context*), '*Girls Only Activity*' (*Activity Context*), '*PA as Punishment*' (*Teacher Behaviours*) and '*Retrieving equipment from multiple access points*' (*Activity Management*) were not observed in any lessons. Within *Lesson Context, Motor Content* (50.2%) was observed in more than half of the SOFIT+ scans followed by *Management* (28.4%) and *Knowledge* (21.4%), while *Skill Practice* (21.4%) made up the largest proportion within *Motor Content*. As for *Activity Context*, *Individual Activity* was observed most often (19.0%), while *Elimination Activity* (1.0%) was observed the least. *Instructs Class* (36.0%) was the most commonly observed teacher behaviour and, together with *Instructs Single Child* (24.8%) and *Instructs Group* (13.2%), instruction time represented the vast majority of the *Teacher Behaviours*. Conversely, *Teacher Behaviours* associated with *Promotes PA* (0.2%) and *Withholding PA* (0.8%) were rarely observed. Lastly, *Activity Management* variables were present in a small proportion of observations in this study (i.e. lower than 5%).

Table 10. SOFIT+ descriptive data

	SOFIT+ Variables	Percentage of scans observed during a lesson Mean (SD)	Percentage of scans observed during Motor Content Mean (SD)
Lesson Context	Management	28.4 (13.9)	
	Knowledge	21.4 (10.8)	
	Motor Content	50.2 (16.4)	
	Fitness	1.6 (3.6)	3.7 (8.3)
	Skill Practice	21.4 (23.3)	42.0 (44.3)
	Game Play	13.0 (21.1)	29.6 (41.1)
	Free Play	0.0 (0.0)	0.0 (0.0)
	Discovery Practice	14.2 (25.3)	24.6 (42.6)
Activity Context	Individual Activity	19.0 (19.1)	37.3 (36.8)
	Partner Activity	13.5 (19.2)	24.4 (32.7)
	Small Sided Activity	4.1 (8.7)	9.2 (20.6)
	Large Sided Activity	6.3 (20.3)	10.1 (27.8)
	Whole Class Activity	7.3 (10.2)	18.9 (29.5)
	Waiting Activity	5.9 (10.4)	14.9 (26.2)
	Elimination Activity	1.0 (4.8)	2.8 (12.9)
	Girls Only Activity	0.0 (0.0)	0.0 (0.0)
	Children Off Task	5.3 (6.2)	9.2 (10.5)
Teaching Behaviours	Supervises	20.2 (11.9)	23.8 (14.5)
	Instructs Single Child	24.8 (12.9)	34.8 (20.3)
	Instructs Group	13.2 (14.6)	15.0 (17.1)
	Instructs Class	36.0 (13.9)	19.1 (14.5)
	Promotes PA	0.2 (1.0)	0.6 (2.6)
	PA as Punishment	0.0 (0.0)	0.0 (0.0)
	Withholding PA	0.8 (3.6)	1.0 (4.8)
	PA Engaged	3.8 (5.5)	5.5 (7.8)
	Off Task	2.0 (2.5)	1.7 (3.8)
Activity Management	Signalling	4.5 (4.1)	6.4 (6.2)
	Retrieving equipment M	0.0 (0.0)	0.0 (0.0)
	Retrieving equipment O	1.0 (2.0)	0.2 (1.0)
	Interruption Public	4.7 (4.1)	2.1 (3.5)
	Interruption Private	3.8 (4.2)	5.5 (7.0)

PA: Physical activity; **M:** Multiple access points; **O:** One access point.

The outputs from the multinomial regression models (i.e. odd ratios and confidence intervals) assessing the association between teaching practices and MVPA can be found in Table 11 for girls and Table 12 for boys. SOFIT+ index was significantly and positively related with children's MVPA (Table 11-12). A 1 unit increase in the SOFIT+ index score was associated with an increased likelihood for both boys and girls to engage in higher MVPA levels than 0-9 s of MVPA (i.e. 10-19 s or 20-29 s or 30-40 s of MVPA) during a 40 s observation scan.

The vast majority of the observed SOFIT+ variables were significantly related to children's MVPA (Table 11-12). During *Management* girls were less likely to engage in 30-40 s rather than in 0-9 s of MVPA compared to when doing *Knowledge* activities. All *Motor Content* variables comprising *Skill Practice*, *Game Play*, *Fitness* and *Discovery Practice* were associated with higher likelihood for children to engage in 10-19 s or in 20-29 s or in 30-40 s of MVPA rather than in 0-9 s of MVPA compared to *Knowledge*.

Table 11. Association between teaching practices and physical activity in girls

	10-19 s		20-29 s		30-40 s	
	OR	95% CI	OR	95% CI	OR	95% CI
Model 1[a]						
SOFIT+ Index	**1.48**	**1.43-1.52**	**1.91**	**1.83-1.99**	**2.47**	**2.32-2.64**
Model 2[a]						
Lesson Context						
Knowledge[1]						
Management[1]	0.99	0.86-1.14	0.88	0.71-1.08	**0.46**	**0.28-0.76**
Skill Practice[1]	**2.31**	**1.97-2.72**	**4.26**	**3.47-5.23**	**5.00**	**3.35-7.48**
Fitness[1]	**2.47**	**1.55-3.95**	**4.74**	**2.73-8.21**	**16.04**	**7.76-33.18**
Game Play[1]	**4.49**	**3.62-5.58**	**12.89**	**9.9-16.78**	**57.93**	**37.5-89.49**
Discovery Practice[1]	**2.5**	**2.03-3.08**	**4.74**	**3.67-6.12**	**8.14**	**5.5-12.06**
Teaching Behaviours						
Instructs Class[2]						
Instructs Single Child[2]	**2.04**	**1.77-2.35**	**3.53**	**2.97-4.2**	**6.06**	**4.52-8.12**
Instructs Group[2]	**1.33**	**1.12-1.57**	**1.95**	**1.59-2.39**	**3.42**	**2.45-4.78**
Supervises[2]	**1.7**	**1.47-1.96**	**2.47**	**2.07-2.96**	**3.78**	**2.79-5.11**
PA Engaged[2]	**1.44**	**1.09-1.89**	**1.76**	**1.26-2.46**	1.47	0.79-2.73
Off Task[2]	**1.7**	**1.19-2.42**	**2.29**	**1.47-3.56**	**3.02**	**1.35-6.76**
Promotes PA	4.2	0.48-36.76	4.23	0.48-37.17	5.21	0.58-47.05
Withholding PA	0.93	0.46-1.86	1.19	0.61-2.32	1.00	0.42-2.37
Activity Management						
Signalling	**2.29**	**1.76-2.99**	**3.16**	**2.37-4.22**	**1.87**	**1.2-2.92**
Retrieving equipment O	0.91	0.53-1.55	**1.99**	**1.14-3.48**	0.83	0.11-6.29
Interruption Public	**0.72**	**0.57-0.91**	**0.34**	**0.23-0.51**	**0.09**	**0.03-0.29**
Interruption Private	1.2	0.89-1.63	**1.47**	**1.08-2.01**	**1.67**	**1.15-2.42**
Model 3[b]						
Activity Context						
Individual Activity[3]						
Partner Activity[3]	**1.92**	**1.48-2.49**	**2.72**	**2.07-3.57**	**2.55**	**1.80-3.61**
Small Sided Activity[3]	**0.68**	**0.47-0.98**	**0.60**	**0.40-0.90**	0.62	0.38-1.01
Large Sided Activity[3]	1.02	0.69-1.49	0.95	0.64-1.42	0.73	0.43-1.23
Whole Class Activity[3]	0.77	0.56-1.04	1.00	0.72-1.38	0.92	0.60-1.41
Waiting Activity	**0.65**	**0.48-0.89**	**0.39**	**0.27-0.54**	**0.19**	**0.11-0.34**
Elimination Activity	0.61	0.21-1.78	**0.19**	**0.06-0.58**	0.75	0.28-2.02
Children Off Task	0.85	0.66-1.08	**0.68**	**0.52-0.89**	**0.60**	**0.42-0.87**

Bold indicates statistically significant relationship ($p < 0.05$); **s:** Seconds**; OR:** Odds ratio; **CI:** Confidence Interval; **PA**: Physical activity; **O:** One access point; **[1]:** Included in Lesson Context dummy variable; **[2]:** Included in Teacher Behaviours dummy variable; **[3]:** Included in Activity Context dummy variable. **[a]:** Model included Teacher ID as covariate; **[b]:** Model included Teacher ID, Lesson Context, Teacher Behaviours and Activity Management variables as covariates.

Table 12. Association between teaching practices and physical activity in boys

	10-19 s		20-29 s		30-40 s	
	OR	95% CI	OR	95% CI	OR	95% CI
Model 1[a]						
SOFIT+ Index	**1.50**	**1.45-1.55**	**1.91**	**1.84-1.99**	**2.53**	**2.39-2.69**
Model 2[a]						
Lesson Context						
Knowledge[1]						
Management[1]	1.00	0.86-1.16	0.85	0.69-1.05	0.66	0.43-1.02
Skill Practice[1]	**2.20**	**1.84-2.64**	**3.89**	**3.14-4.82**	**8.99**	**6.15-13.13**
Fitness[1]	**1.78**	**1.06-2.98**	**3.58**	**2.04-6.27**	**17.41**	**8.87-34.18**
Game Play[1]	**4.36**	**3.47-5.48**	**8.44**	**6.46-11.03**	**57.88**	**37.76-88.71**
Discovery Practice[1.]	**3.08**	**2.49-3.81**	**6.75**	**5.26-8.66**	**11.85**	**8.09-17.36**
Teaching Behaviours						
Instructs Class[2]						
Instructs Single Child[2]	**2.01**	**1.72-2.35**	**3.48**	**2.90-4.18**	**7.60**	**5.80-9.96**
Instructs Group[2]	**1.28**	**1.07-1.52**	**2.20**	**1.79-2.70**	**3.45**	**2.53-4.71**
Supervises[2]	**1.84**	**1.58-2.15**	**2.82**	**2.35-3.39**	**4.30**	**3.25-5.68**
PA Engaged[2]	**2.05**	**1.51-2.78**	**1.59**	**1.09-2.32**	**2.48**	**1.51-4.09**
Off Task[2]	1.19	0.81-1.74	**1.78**	**1.13-2.78**	**2.91**	**1.46-5.80**
Promotes PA	0.45	0.04-5.14	1.56	0.27-9.06	4.07	0.77-21.60
Withholding PA	0.76	0.45-1.27	**0.54**	**0.32-0.92**	**0.29**	**0.13-0.63**
Activity Management						
Signalling	**2.56**	**1.91-3.43**	**3.20**	**2.35-4.37**	**1.89**	**1.22-2.91**
Retrieving equipment O	1.66	0.96-2.87	**2.38**	**1.32-4.27**	1.78	0.51-6.14
Interruption Public	**0.68**	**0.53-0.88**	**0.30**	**0.20-0.46**	**0.09**	**0.03-0.26**
Interruption Private	1.22	0.86-1.72	1.26	0.88-1.79	1.30	0.87-1.93
Model 3[b]						
Activity Context						
Individual Activity[3]						
Partner Activity[3]	**1.94**	**1.44-2.63**	**2.77**	**2.05-3.75**	**2.87**	**2.04-4.04**
Small Sided Activity[3]	**1.65**	**1.04-2.61**	1.00	0.61-1.63	1.68	0.98-2.88
Large Sided Activity[3]	0.94	0.62-1.43	1.07	0.71-1.64	1.16	0.71-1.89
Whole Class Activity[3]	1.00	0.70-1.43	0.94	0.65-1.37	**2.03**	**1.34-3.07**
Waiting Activity	**0.48**	**0.33-0.70**	**0.35**	**0.24-0.51**	**0.09**	**0.05-0.15**
Elimination Activity	**0.22**	**0.08-0.66**	**0.09**	**0.03-0.27**	**0.20**	**0.08-0.51**
Children Off Task	**0.75**	**0.57-0.98**	**0.73**	**0.55-0.96**	0.88	0.63-1.21

Bold indicates statistically significant relationship ($p < 0.05$); **s:** Seconds**; OR:** Odds ratio; **CI:** Confidence Interval; **PA**: Physical activity; **O:** One access point; **[1]:** Included in Lesson Context dummy variable; **[2]:** Included in Teacher Behaviours dummy variable; **[3]:** Included in Activity Context dummy variable. **[a]:** Model included Teacher ID as covariate; **[b]:** Model included Teacher ID, Lesson Context, Teacher Behaviours and Activity Management variables as covariates.

As concerns *Activity Context*, during *Partner Activity* children were more likely to engage in 10-19 s, 20-29 s or 30-40 s of MVPA rather than in 0-9 s of MVPA compared to *Individual Activity*. Girls were less likely to spend 10-19 s or 20-29 s in MVPA rather than in 0-9 s of MVPA during *Small Sided Activity* compared to when engaged in *Individual Activity*. Conversely, boys were more likely to spend 10-19 s in MVPA rather than in 0-9 s of MVPA during small-sided activities compared to when engaged in *Individual Activity*. Furthermore, boys were more likely to spend 30-40 s in MVPA rather than in 0-9 s of MVPA during *Whole Class activity*. *Waiting Activity*, *Elimination Activity* and *Children Off Task* were generally associated with lower likelihood for children to participate in more than 10 s of MVPA compared to 0-9 s of MVPA. In particular, *Waiting Activity* presented the lowest odd ratios where girls and boys were 0.19 and 0.08 times as likely respectively to engage in 30-40 of MVPA compared to 0-9 s of MVPA.

As for the *Teacher Behaviours*, *Supervises*, *Instructs Single Child*, *Instructs Group* and *Off Task*, were associated with higher likelihood for both boys and girls to engage in 10-19 s (excluding boys Off Task) or in 20-29 s or 30-40 s of MVPA rather than in 0-9 s of MVPA compared to *Instructs Class*. Similarly, when the teacher/coach was engaged in PA (*PA Engaged*) all children were more likely to spend 10-19 s or 20-29 s or 30-40 s in MVPA rather than in 0-9 s of MVPA. Teacher *Withholding PA* was associated with lower likelihood for boys to engage in 30-40 s of MVPA compared to engaging in 0-9 s of MVPA, while *Promotes PA* had no significant relation with MVPA engagement.

As concerns *Activity Management*, when *Signalling* was observed both girls and boys were more likely to spend 10-19 s or 20-29 s or 30-40 s in MVPA rather than in 0-9 s of MVPA. Similarly, *Retrieving equipment from one access point* was associated with increased likelihood for children to engage in 20-29 s of MVPA. Conversely, *Interruption Public* was associated with decreased likelihood for both girls and boys to spend 10-19 s, 20-29 s and 30-

40 s in MVPA, rather than in 0-9 s in MVPA. *Interruption Private* was related with increased likelihood to engage in 20-29 s and 30-49 s in Girls Only.

Discussion

This study aimed to assess the validity of SOFIT+ as an observation tool to assess teaching practices and competencies related with young children's MVPA engagement during PE. Most of the SOFIT+ categories were associated with children's engagement in MVPA and the associations were generally in line with the hypotheses formulated in the first SOFIT+ validation paper (Weaver et al., 2016). The new SOFIT+ variables proposed in this study comprising *Discovery Practice*, *Instructs Class*, *Instructs Group* and *Instructs Single Child* were associated with MVPA following the direction hypothesised, though no significant association was found for *Large Sided Activity*. Furthermore, this was the first study to evaluate the association between SOFIT+ *Activity Management* teaching practices variables and children's PA, finding both positive and negative associations with MVPA where interrupting the class to address misbehaviours presented the strongest negative association with MVPA.

SOFIT+ reliability

All the observed SOFIT+ categories presented levels of inter-rater reliability with percentage of agreement above 80% and Cohen's Kappa ranging from fair to almost perfect. *Free Play*, *Girls Only Activity*, *PA as Punishment* and *Retrieving equipment from multiple access points* were not observed in this study and therefore inter-rater reliability could not be assessed. However, inter-rater reliability for *Elimination Activity*, *Girls Only Activity* and *Retrieving equipment from multiple access points* was evaluated within observers training for this study (Supplementary material 5) and in previous studies (Weaver et al., 2016; Fairclough et al., 2018), while the absence of *PA as Punishment* was a positive finding that is in line with best practices in PE (Barney et al., 2016).

SOFIT+ validity

As observed in previous SOFIT+ validations (Weaver et al., 2016; Fairclough et al., 2018), an increase in the SOFIT+ index was associated with higher MVPA engagement in children, meaning that the presence of what was classified in this study as MVPA promoting teaching practices together with the absence of MVPA restricting teaching practices was associated with improved MVPA in PE. The strength of the relationship between SOFIT+ index and MVPA increased with increasing length of MVPA bouts suggesting that children were most likely engaged in 30 s or more of MVPA over a 40 s scan when greater MVPA promoting and lower MVPA restricting teaching practices were observed.

Within *Lesson Context* category, all *Motor Content* variables were associated with a higher likelihood for children to engage in MVPA compared to Knowledge and *Management*, and the strength of the relationship increased with increasing length of MVPA bouts, suggesting that all *Motor Content* categories were positively related with MVPA. *Skill Practice* was associated with positive engagement in 30-40 s MVPA in contrast with what was hypothesised and found by Weaver et al. (2016) who classified *Skill Practice* as a MVPA restricting variable and contrary to Fairclough et al. (2018). Weaver et al. (2016) and Fairclough et al. (2018) used hip-worn GT3X ActiGraph accelerometers and count-based metrics to measure MVPA while wrist-worn GT9X ActiGraph accelerometers and raw accelerations metrics were used in this study. It was reported that hip-worn accelerometers do not adequately capture MVPA during object control skills differently from wrist-worn accelerometers (Sacko et al., 2019) and that GT3X and GT9X accelerometers can lead to different and non-equivalent PA output based on the metrics used (Clevenger et al., 2020).

Therefore, it is possible that MVPA was underestimated during *Skill Practice* object-control activities in Weaver et al. (2016) and Fairclough et al. (2018) studies. Furthermore, in support of findings of this study, many of the activities observed in the current study during *Skill Practice* such as catching or throwing the ball, kicking the ball, jumping and engaging in obstacle or locomotor courses were classified as MVPA within the Youth Compendium of physical activities (Butte et al., 2018). *Skill Practice* presented a slightly lower association with MVPA compared to other *Motor Content* categories that could be explained by the co-occurrence of waiting activities. *Game Play* was associated with the highest likelihood for children to engage in MVPA followed by *Fitness*. This finding is consistent with previous SOFIT+ studies (McKenzie et al., 1992; Weaver et al., 2016) and previous research reporting that *Game Play* is associated with high levels of MVPA (Wood and Hall, 2015; Tanaka et al., 2018). Within this study, *Fitness* generally consisted of warm-up or cool down activities that aligned with best practices in PE involving general aerobic activities and flexibility exercise that could have led to lower MVPA engagement compared to *Game Play* (Faigenbaum, 2007). *Discovery Practice* was associated with increased MVPA levels in children as hypothesized in this study with higher likelihood for children to engage in MVPA compared to *Skill Practice* but lower likelihood compared to *Game Play* and *Fitness*. This is in line with previous literature suggesting that creating conditions for children to be autonomous could lead to high motivation to engage in PA within PE (Zarazaga Raposo et al., 2020).

Activity Context variables can be observed only during *Motor Content*, therefore, the association between *Activity Context* categories and MVPA within SOFIT+ scans including *Motor Content* only was evaluated (Table 11-12). Compared to *Individual Activity*, *Partner Activity* was associated with higher likelihood for both boys and girls to engage in MVPA while *Small Sided Activity* was associated with higher likelihood for boys to engage in 10-19 s of MVPA confirming the results from previous SOFIT validations (Fairclough et al., 2018).

Whole Class Activity was associated with higher likelihood for boys to engage class 30-40 seconds of MVPA compared to *Individual Activity* in contrast with previous research (Weaver et al., 2016; Fairclough et al., 2018). This could be due to whole class activities typical of this age group such as tag games being related with high levels of MVPA (Butte et al., 2018). *Large Sided Activity* did not show any significant association with MVPA promotion compared to *Individual Activity*. *Children Off Task* was related with lower levels of MVPA in both boys and girls. This could be because children off task might engage in a variety of behaviours that could include disengagement or disruptive conduct that could lead to low PA engagement (Goyette et al., 2000; Lyngstad et al., 2016). *Waiting Activity*, *Elimination Activity* and *Children Off Task* were related with lower likelihood in both girls and boys to engage in MVPA in line with what hypothesised in this study and consistently with findings from previous SOFIT+ validation studies.

For *Teacher Behaviours*, the categories *Supervises*, *Instructs Single Child*, *Instructs Group*, *PA Engaged* and *Off Task* were associated with higher levels of MVPA engagement in children compared to *Instructs Class*. This matched what expected as children are normally asked to stand still while the teacher is providing instructions to the whole class leading to low MVPA. Conversely, *Instructs Single Child* and *Instructs Group* were strongly related with children's increased MVPA engagement, with *Instructs Single Child* being the strongest predictor of MVPA engagement. The explanation of this finding could be that the children who were not involved in the teacher instruction were engaged in high MVPA levels. This demonstrates the importance to differentiate Instruction time based on the number of children involved as different groupings are associated with different MVPA engagement. Despite being classified as a barrier to PA, teacher *Off Task* was associated with positive MVPA engagement with similar odds ratios compared to Supervising, suggesting that teachers attended other duties when they were sure that PE activities were under control or that children maintain MVPA engagement even if the teacher is not watching. Conversely, *Withholding PA* was associated with low levels of MVPA in line with what was hypothesised, however, this was true for boys only and the reason behind it could be that only boys were asked to withhold from PA within this study. *Promotes PA* had no association with MVPA in children and that could be due to the very low number of observations of this behaviour in this study (0.3% of total observations) suggesting more attention should be given to verbal promotion of PA by PE teachers in primary school.

As concerns *Activity Management*, *Signalling* (e.g. Teacher tells children to stop an activity and sit down) was positively associated with MVPA engagement however children were more likely to engage in 10-19 or 20-29 s of MVPA rather that 30-40 s. The explanation to this finding could be that children were normally engaged in *Motor Content* activities during the first phase of the SOFIT+ scan before receiving a signal from the teacher to stop as *Signalling* was recorded in Phase 2 of SOFIT+ scans. *Retrieving equipment from one access point* was associated with higher likelihood for children to spend 20-29 s in MVPA suggesting that retrieving equipment is related to lower MVPA levels than *Motor Content* activities. Interrupting the class publicly was associated with decreased MVPA levels in line with what was hypothesised. However, interrupting privately was positively associated with MVPA, and this is consistent with what was found in this study for *Instructs Single Child*, where interacting with a child did not lead to decrease in class MVPA levels.

Observed teaching practices compared to previous literature

Motor Content was recorded more often (50.2% of the observations) than *Management* (28.4%) and Knowledge (21.4%) within the current study in conformity with previous studies using SOFIT and SOFIT+ in primary school children (Gharib et al., 2015; Stylianou et al., 2016; Weaver et al., 2016; Fairclough et al., 2018; Kwon et al., 2020). Within previous studies using SOFIT and SOFIT+ children spent the highest amount of time in *Game Play* followed by *Skill Practice*, *Fitness* and *Free Play* while in studies using SOFIT+ *Game Play* and *Fitness* obtained the highest percentages (Gharib et al., 2015; Stylianou et al., 2016; Weaver et al., 2016; Fairclough et al., 2018; Kwon et al., 2020). Differently, in this study higher percentages of *Skill Practice* were observed and *Skill Practice* presented higher percentages compared to other *Motor Content* categories. The reason for this could be that data were collected within the SAMPLE-PE project where PE interventions were aimed at improving motor competence (Rudd et al., 2020a). Given that *Discovery Practice* was included within *Motor Content* in this study, it is difficult to make a comparison with previous studies.

As concerns *Activity Context*, *Individual Activity* (19% of observations) was observed more times than other categories in line with Weaver et al. (2016) study (71.7% of observations) but with lower percentages. Furthermore, lower percentages of *Elimination Activity* (1.0% of observations) and *Waiting Activity* (5.9% of observations) were observed compared to Weaver et al. (2016) (8.8% of observations for *Elimination Activity* and 11.2% of observations for *Waiting Activity*), which is a positive factor for MVPA promotion during PE.

As for *Teacher Behaviours*, both in the current study and the study from Weaver et al., (2016) more than 70% of the SOFIT+ scans included instruction. However, this study divided instruction time in *Instructs Class* (36.0%), *Instructs Single Child* (24.8%) and *Instructs Group* (13.2%). The fact that the three teacher instruction targets were observed consistently strengthen the rationale for the inclusion of these categories in the SOFIT+.

Strengths and limitations

This study presented multiple strengths comprising the inclusion of a high amount of PE lessons compared to previous SOFIT+ validation studies and the assessment of the validity concerning *Activity Management* variables that have never been validated in previous research.

Another strength consisted in the use of statistical models that are more sophisticated compared to the ones employed in previous SOFIT+ validation studies as statistical models in this study accounted for teaching practices happening simultaneously (Weaver et al., 2016; Fairclough et al., 2018). A further strength was the use of 1 second epoch MVPA assessment that best fits the sporadic and variable nature of PA in 5-6 years old children. The main limitation of this study is that it was possible to monitor MVPA levels only in 50% of the participants providing consent to participate in the study because of time and resources constraints. Therefore, it can only be inferred the MVPA levels assessed in the participants of this study are representative of Class MVPA levels. Other limitations are that some of the activities comprising *Free Play*, *Girls Only Activity*, *PA as Punishment* and *Retrieving equipment from multiple access points* were never observed and that the sample of this study only included 5-6 years old children living in deprived areas of North West England, limiting the generalizability of results. Lastly, the lack of an intra-rater reliability assessments is a limitation of both this study and previous SOFIT+ validation studies (McKenzie and Mars, 2015; Weaver et al., 2016; Fairclough et al., 2018).

Future directions

To facilitate the assessment of validity and reliability of teaching practice assessment, future validation studies should make sure that all teaching practices are observed multiple times during the data collection phase (e.g. by designing PE lessons including specific teaching practices) and should measure PA in most of the children participating in each PE lesson observed. Furthermore, future validation studies should consider to assess intra-rater reliability as well as inter-rater reliability to gain better information about SOFIT+ measurement accuracy (McKenzie and Mars, 2015). Despite the current version of the SOFIT+ takes in consideration aspects of both teacher-centred and student-centred approaches, future studies should clarify whether teacher-centred or student-centred approaches in PE lead to different MVPA levels in children (Lonsdale et al., 2013; Errisuriz et al., 2018). Furthermore, SOFIT+ does not consider the motivational climate created by the teacher during PE that could potentially influence children MVPA engagement in PE. Empowering motivational climates (i.e. teacher support of autonomy, task-involving, relatedness and structure; (Duda, 2013)) foster enjoyment, persistence and intrinsic motivation (Duda, 2013). Intrinsic motivation has been found to positively predict MVPA (Gunnell et al., 2016) while fostering autonomy, competence and relatedness (basic psychological needs) has associated positively with MVPA in children within PE (Gunnell et al., 2016). In contrast, disempowering motivational climates (i.e. teacher supports controlling, ego-involving and relatedness thwarting (Duda, 2013)) were associated with increased anxiety, avoidance, and decrease in effort (Duda, 2013), which could lead to lower MVPA. Therefore, future observation tools could integrate the assessment of teaching practices associated with motivational climate to facilitate a better understanding around how best to support children's MVPA during PE (Van den Berghe et al., 2014).

Conclusion

This study confirmed that teaching practices are associated with children’s MVPA engagement in PE and provide valuable information about how teachers could maximise children’s MVPA engagement (e.g. limiting time spent in management activities and class instruction, avoiding or minimizing elimination and waiting activities or engaging in PA activity with children). Based on the outcome of this study SOFIT+ can be considered a valid and reliable tool to assess teaching practices related with MVPA in primary school children and the modification made to the observation tool were considered appropriate for the age group included in this study. Therefore, SOFIT+ was used in study 3 within this thesis. SOFIT+

could be used in future research focusing on PE teaching or coaching behaviours to evaluate common teaching and coaching practices, to help clarify best teaching practices for MVPA promotion and to evaluate PE teaching or coaching interventions in children. Furthermore, researchers or practitioners could use SOFIT+ to assess the effect of teacher trainings on teaching practices associated with MVPA promotion. Lastly, SOFIT+ could be a user friendly and feasible tool for practitioners to monitor and evaluate teaching practices to increase children's MVPA. Future research should evaluate the association of teacher-centred and student-centred teaching approaches in PE with MVPA while future observation tools assessing teaching practices in PE or coaching should consider to include aspects concerning the motivational climate created by the teachers.

Chapter 5: Study 3

Teacher physical activity promoting practices and children’s physical activity within physical education lessons underpinned by movement learning theory (SAMPLE-PE)

Thesis study map: Chapter 5

Study	Objectives / Main outcomes
Study 1: Development of raw acceleration cut-points for wrist and hip accelerometers to assess sedentary behaviour and physical activity in 5-7 year old children	*Main outcomes:* • The raw acceleration cut-points developed for GT9X ActiGraph devices presented acceptable validity and reliability for hip, dominant wrist and nondominant hip placement to assess SB, LPA, MPA and VPA in 5-7 year old children. • Different accelerometer wear position - hip, dominant wrist or nondominant wrist – offer similar accuracy in estimating PA/SB.
Study 2: Validation of modified SOFIT+: relating physical activity promoting practices in physical education to moderate-to-vigorous physical activity in 5–6 year old children.	*Main Outcomes:* • The modified version of the SOFIT+ demonstrated to be a valid and reliable tool to assess teaching practices associated with MVPA in 5-6 years old children in UK. • The new SOFIT+ teaching variables (*Discovery Practice, Instruction Class, Instruction Group, Instruction Single Child* and *Large sided PA*) demonstrated reliability and were generally associated with children's PA in the expected directions. • The *Activity Management* teaching practices comprising *Signalling*, *Retrieving equipment from one access point*, *Interruption Public*, and *Interruption Private* were generally associated with decreased children's MVPA engagement during PE.
Study 3: Teacher physical activity promoting practices and children's physical activity within physical education lessons underpinned by motor learning theory (SAMPLE-PE)	*Objectives:* • To assess children's MVPA in PE within Linear Pedagogy and Nonlinear pedagogy and to compare this to current practice within PE delivery in primary schools. • To assess teaching practices associated with PA in PE within Linear Pedagogy and Nonlinear pedagogy and to compare this to current practice within PE delivery in primary schools.
Study 4: Effect of Linear and Nonlinear pedagogy physical education interventions on children's physical activity: a cluster randomized controlled trial (SAMPLE-PE)	*Objective:* • To evaluate the effect of PE interventions guided by Linear pedagogy and Nonlinear pedagogy on habitual PA over the whole week and different segments of the week compared to the control group (current practice in PE) in 5–6-year-old children.

Thesis context

This study concerned the process evaluation of the SAMPLE-PE project randomized controlled trial from a PA perspective (see Chapter 1: "*Overview of the SAMPLE-PE project*", page 33). The non-dominant wrist cut-points developed in study 1 (Chapter 3) were used in this study to assess children's MVPA during PE. Furthermore, the modified version of the SOFIT+ validated in study 2 (Chapter 4) was employed to assess teaching practices associated with MVPA in PE.

Introduction

Physical education (PE) should provide varied, meaningful and developmentally appropriate learning experiences for children to acquire the attributes needed to lead physically active lives (Australian Curriculum Assessment and Reporting Authority, 2013; UK Department of Education, 2013; SHAPE America, 2015; UNESCO, 2015; afPE, 2020). Given the well-established health benefits of participation in moderate-to-vigorous physical activity (MVPA) for children (Donnelly et al., 2016; Lubans et al., 2016; Poitras et al., 2016; Tarp et al., 2016), public health related arguments have been made that PE lessons should be physically active and involve teaching physical, cognitive, social and emotional skills in and through movement (Sallis et al., 2012). This health-related rationale led to the development of a goal for students to spend at least 50% of the PE lesson time engaged in MVPA (U.S. Public Health Service, 1991), a guideline which has subsequently been adopted by several PE organisations across the globe (Pate et al., 2006; AAHPERD, 2013; afPE, 2020). Despite these ambitions, recent research shows that students only spend between 9.5% and 42.4% of PE time engaged in MVPA (Wood and Hall, 2015; Costa et al., 2016; Weaver et al., 2017; Tanaka et al., 2018). While it is important to acknowledge that the focus on MVPA should not come at the expense of other important and meaningful PE learning outcomes (Beni et al., 2017; Dudley et al., 2020), monitoring MVPA levels during PE lessons is important to track progress against this high quality PE indicator and to maximise meaningful physical activity (PA) opportunities during PE (Hollis et al., 2016; Dudley et al., 2020).

Children's MVPA levels in PE can be affected by numerous factors, including the proportion of boys and girls in the class, lesson content (e.g. ball games, fitness, dance), lesson location (e.g. outdoors, indoors) (McKenzie et al., 1995; Costa et al., 2016; Tanaka et al., 2018). Teaching practices also play a central role in determining children's MVPA during PE lessons through teachers' decisions on movement content, time management (e.g. the amount of time spent explaining a task, or the amount of time before moving to a different task) and delivery (e.g. enthusiastic verbal promotion of PA engagement). PE teachers with higher levels of pedagogic content knowledge (i.e. teachers being able to deliver PE using different pedagogical approaches where pedagogy is defined as interdependent elements of curriculum design, learning and teaching (Armour, 2011)) and positive attitudes towards PA promotion are generally more effective in promoting PA during PE (McKenzie et al., 1997; Telford et al., 2016). Levels of PE teachers pedagogic content knowledge also play a central role in their strategic decisions about teaching practices that foster children's PA (Haerens et al., 2011; Ennis, 2016). Nevertheless, few studies have examined the association between different pedagogical approaches in PE and student MVPA levels. Thus, to maximise meaningful PA opportunities during PE, examining the extent to which teaching practices support students' MVPA under different pedagogical conditions is warranted.

An important feature of meaningful PE experiences and a key objective for early primary PE curricula (5-to-7-years-old) is the development of foundational movement skills needed for a lifetime of diverse PA opportunities (Australian Curriculum Assessment and Reporting Authority, 2013; UK Department of Education, 2013; Beni et al., 2017). Developing a wide range of foundational movement skills (e.g. catching, jumping, swimming, cycling) supports children engage in a wide range of PAs (Seifert et al., 2016; Hulteen et al., 2018). However, movement skills do not develop by maturation alone, children need to be physically active within favourable conditions for movement skills to emerge such as structured teaching and learning activities (Gallahue et al., 2012). The more a child moves the greater the opportunity to develop and acquire competence in movement skills (Stodden et al., 2008; Robinson et al., 2015), which in turn should lead to enhanced engagement in PA (Stodden et al., 2008; Robinson et al., 2015; Hulteen et al., 2018). Therefore, from a PE perspective, pedagogical approaches aimed at fostering movement competence should also seek to maximise opportunities for students to be physically active.

Pedagogical models designed for movement development can be highly beneficial for teachers and children as they provide a guide for PE practice to achieve valuable learning outcomes (Chow et al., 2011; Kirk and Haerens, 2014; Ennis, 2016; Metzler, 2017). Linear and Nonlinear pedagogy are two pedagogical approaches underpinned by different theories of motor learning that can guide the design of PE lessons aiming to foster the development of movement competence. Linear pedagogy is based on the Information Processing learning Theory (Schmidt, 1975). In this perspective, a learner is seen as a system that elaborates perceptual-motor inputs to produce movement outputs (Gallahue et al., 2012). Furthermore, learners participate in a set of planned movement experiences of increasing difficulty to obtain specific learning outcomes (Gallahue et al., 2012). A central aspect of Linear pedagogy is to prioritise learning in the psychomotor domain through the repetition of movement tasks as repetition leads to movement automatization and therefore to increased accuracy and decreased cognitive load while performing the practiced task (Fitts and Posner, 1967; Taylor and Ivry, 2012). Therefore, a key role of the teacher is to design activities and provide instructions that are appropriate for children's proficiency level (Fitts and Posner, 1967; Taylor and Ivry, 2012). Accordingly, Linear pedagogy is characterised by a teacher-centred approach to PE, where the teacher is the main source of instructional content and leads the performers through a series of pre-determined learning outcomes (Gallahue et al., 2012; Metzler, 2017). In line with its theoretical foundation, Linear pedagogy includes the following characteristics: a) children should learn the optimal movement patterns demonstrated by the teacher; b) movement skills should be broken down into simpler movements to facilitate learning; c) movement variability within a task is seen as detrimental for learning and therefore should be reduced (Fitts and Posner, 1967; Metzler, 2017).

Nonlinear pedagogy is based on Ecological Dynamics theoretical and philosophical foundations (Araújo et al., 2006; Warren, 2006). From an Ecological Dynamics perspective learners are seen as complex neurobiological systems in mutual and reciprocal synergy with the environment that learn through perception and action coupling processes (Araújo et al., 2006; Warren, 2006; Chow et al., 2011). More specifically, perception and action coupling (or information-movement coupling) processes consist in the continuous creation of functional affordances (opportunities for action) within a cyclical process of perception and action leading to the emergence of goal-directed behaviours (Chow, 2013). Based on this pedagogy, children are provided with the possibility to explore different movement solutions within carefully designed learning environments. Proponents of this approach argue this leads to a continuous process of perception and action coupling, resulting in the emergence of functional movement solutions as children respond to different situations by selecting an appropriate movement output (Chow et al., 2011). Consequently, Nonlinear pedagogy is reported as a learner-centred PE approach where children are provided with high levels of autonomy and are invited to explore different movement solutions, while teachers channel learning by modifying constraints (Chow and Atencio, 2014). Assumptions of Nonlinear pedagogy in instructional settings include the following: a) movement skills should be practiced in a situation that is representative of a game environment or performance condition, b) movement skills should emerge by the interaction between individual and environment in a movement perception action coupling: c) teachers modify individual, task and environmental constraints to channel movement skills learning; d) Movement variability is encouraged; e) teachers should foster an external focus of attention (Chow and Atencio, 2014; Correia et al., 2019).

In summary, determining MVPA levels of children in PE and examining associated teaching practices can provide important information to assess adherence to guidelines associated with high quality PE. Movement competence is a key outcome for primary PE and a feature of meaningful PE experiences for children. As movement development emerges through PA, research examining MVPA promotion during PE within pedagogical approaches focused on movement competence is warranted. Such research could inform strategies to maximise meaningful opportunities to be physically active within PE lessons taught through these pedagogies. To date, no study has examined children's MVPA and teaching practices during PE in Linear and Nonlinear PE pedagogical approaches focused on movement competence development. Therefore, this study aimed to assess children's MVPA and teaching practices in primary PE within Linear Pedagogy and Nonlinear pedagogy and to compare this to current practice within PE delivery in primary schools.

Methods

Design

This study was approved by the University Research Ethics Committee (Reference 17/SPS/031) and formed part of the process evaluation of the Skill Acquisition Methods fostering Physical Literacy in Early Primary Education (SAMPLE-PE) cluster randomised controlled trial (ClinicalTrials.gov identifier: NCT03551366), which is described in detail elsewhere (Rudd et al., 2020a). Briefly, SAMPLE-PE aimed to investigate the efficacy of PE curricula based upon different pedagogical principles and motor learning theories in promoting physical literacy amongst 5-6-year-old children. 119 primary schools situated in deprived areas of a large metropolitan city in North West England were invited to take part in the study. Head-teachers from 12 primary schools provided gatekeeper consent and written parental consent and child assent were obtained for 360 5–6-year-old children (55% girls) from year 1 classes to participate in the research. Children without consent to take part in the study continued to participate in the PE lessons. Children who were not able take part in PE due to reasons such as medical conditions, profound learning disabilities or special educational needs were not eligible to take part in this study. Using a computer-generated procedure, schools were randomly allocated to one of three groups: i) Nonlinear pedagogy PE intervention (n = 3 schools); ii) Linear pedagogy PE intervention (n = 3 schools); or iii) control group (n = 6 schools). Following baseline assessments, intervention schools received a 15-week PE curriculum intervention delivered by trained coaches, while control schools followed usual practice (described in detail below). All groups were asked to provide the same dose of PE (i.e. 2 × 60 min weekly PE lessons, for 15 weeks).

Outcome data were collected at baseline (T0), immediately post-intervention (T1), and 6 months after the intervention has finished (T2). The process evaluation methods have been published in the study protocol (Rudd et al., 2020a), and only relevant methods for the current study analyses are outlined below. For feasibility and time constraint reasons, a convenience sample of 50% of the children who provided consent to participate in the SAMPLE-PE project within 9 schools (comprising 3 Nonlinear intervention schools, 3 Linear intervention schools and 3 randomly selected control schools) were recruited for this study.

Intervention

Coaches were recruited and trained to deliver Linear or Nonlinear pedagogy interventions (Rudd et al., 2020a). Both Linear and Nonlinear pedagogy PE curricula were delivered over 2 lessons a week for 15 weeks leading to a total of 30 PE lessons per class divided in 3 content blocks of 10 lessons (each block lasting 5 weeks) focusing sequentially on dance, gymnastics and then ball skills, respectively. Teachers and coaches within control schools delivered PE as usual 2 times a week over 15 weeks.

Deliverer training and intervention delivery

Intervention deliverers were recruited from a University in the North-West of England with a longstanding reputation for delivering high quality BA (Hons) Physical Education and BSc (Hons) Sport Coaching undergraduate and postgraduate degree programmes. As a result, two sport coaches from the research team and three sport coaches who each possessed at least a level 2 coaching qualification, were recruited and agreed to participate in a series of training sessions, to support the delivery of the SAMPLE-PE interventions. Before commencing the training, each of the coaches was observed by a member of the research team while delivering a PE lesson in a primary school not involved in the SAMPLE-PE project. The coaches were then assigned to either a Linear (n=2) or Nonlinear (n=3) curriculum training programme based on their observed pedagogical approaches. The training for each pedagogy was designed to incorporate both practical and theoretical elements and was delivered by members of the research team with expertise in these approaches. Each training session lasted approximately 180 minutes and was conducted over a period of five weeks. During the training programme the coaches had the opportunity to be observed leading a PE lesson with Year 2 children (6-7-years-old) within a primary school not participating in the SAMPLE-PE project. Following these lessons, the coaches received augmented feedback from members of the research team. They were also encouraged to reflect on their pedagogic practice and encouraged to develop strategies to improve their own self-analysis. Following the training period coaches received a pedagogical framework and a resource pack together with the material used during the sessions and recordings of the practical sessions. The PE lessons were planned considering equipment available or that could be made available in each one of the participating schools (see examples in supplementary material 6-7).

Linear pedagogy intervention delivery

Linear pedagogy PE lessons were designed following the principles of Information Processing theory and informed by concepts of direct instruction (Metzler, 2017) and followed a structure involving: 1) a teacher-led warm-up activity, 2) practicing movement skills within drills, 3) a performance or game activity to apply the movement skills learnt during the lesson 4) a cool down (Supplementary material 6). Within a Linear pedagogy approach, coaches were expected to plan learning tasks and provide clear verbal instructions and visual demonstrations to provide the children with a 'picture' of what proficient movement looked like. During early learning of a movement skill the coaches were encouraged to review previously learned material and to provide corrective feedback during each activity with particular attention to children reiterating mistakes. Furthermore, coaches were trained to use Fitts and Poster's cognitive stages (cognitive, associative, autonomous) (Fitts and Posner, 1967) to evaluate children's progression in movement skills proficiency and to change the difficulty of the tasks based on children's skill level. Children were invited to perform and repeat movement skills as previously demonstrated by the teacher and once the skill showed signs of automaticity were encouraged to practice independently in increasingly open environments. Gentile's taxonomy principles together with the Challenge Point framework (Adams, 1999; Guadagnoll and Lee, 2004) were used by the teachers to facilitate these progressions of skill practice into more open environments.

Nonlinear pedagogy intervention delivery

The Nonlinear pedagogy intervention was designed in line with Ecological Dynamics theories (Chow et al., 2011). Each PE lesson started with children exploring the PE hall and different equipment within the environment (e.g. benches, mats, hoops, cones). The lesson continued with activities where teachers introduced variability by changing constraints and tasks designed to be representative of a real game, sport or performance situations in order to create different functional opportunities for action (affordances) for children (Supplementary material 7). Coaches were asked to use the Space Task Equipment People (STEP) framework to identify and modify constraints within the lessons (STEP Academy Trust, 2015). Furthermore, coaches were trained to use Newell's stages of motor learning (coordination, control and skill) to monitor children's progress in movement learning and to modify and individualise constraints based on the motor learning stages observed (Newell, 1986). Demonstrations or corrective feedback were not used during activities, alternatively, coaches invited children to reflect using questioning strategies or to observe their peers. Coaches were encouraged to use dialogue as a strategy to foster an external focus of attention in the child to infuse variability in the task and channel children learning (e.g. how can you make a pass that is easier to catch for your teammate? How many ways to move on the mat can you find?).

Measures and procedures

The following paragraph repeats information reported in Study 2 within the "Procedures" section (page 129).

Child anthropometric and demographic data were collected at schools during baseline assessments (between January and February 2018), within a two-week period before the start of the intervention. Children's PA levels (accelerometers), teacher practices related to PA (video observation) and pedagogical fidelity (video observation) were assessed during PE lessons as part of the SAMPLE-PE process evaluation between February and June 2018 (Rudd et al., 2020a). Specifically, three PE lessons in each year 1 class (1 lesson every 5 weeks) were randomly selected for data collection. Each of the intervention groups and the control group included five Year 1 classes. Therefore, 45 lessons (15 per group) were scheduled to be evaluated. Schools were informed about the data collection schedule before the beginning of the trial.

Anthropometrics

Body mass was assessed to the nearest 0.1 kg using scales (model 760, Seca, Hamburg, Germany) while stature was assessed using stadiometers to the nearest 0.1 cm (The Leicester Height Measure, Child Growth Foundation, Leicester, United Kingdom) (Dettwyler, 1993). All anthropometric measurements were taken twice while a third measurement was taken in case the first two measurements differed by more than 1% and subsequently the mean between the measurements was taken. Body mass index (BMI) was calculated using stature and mass measurement and then it was converted to standardised BMI z-scores following international Obesity task force (IOTF) classification (Cole and Lobstein, 2012).

Demographics

Children's demographic data (i.e. date of birth, gender, ethnicity, household postcode) were collected using questionnaires that parents filled and returned together with the consent form. Children's neighbourhood deprivation rank and decile were calculated from household postcode using the English indices of deprivation (UK Government Ministry of Housing Communities & Local, 2018).

Physical activity measurement

The following paragraph repeats information reported in Study 2 within the "Physical activity assessment" section (page 130).

ActiGraph GT9X (ActiGraph, Pensacola, FL, USA) were used to assess PA in children during PE. Before the beginning of each lesson, ActiGraph GT9X accelerometers were fitted on each participant’s non-dominant wrist to assess their PA levels during the lesson. If one of the randomly selected children was absent another participant to the SAMPLE-PE project was randomly selected to wear an accelerometer. Accelerometers were set to record accelerations at 100Hz over 1 second epochs within a range of ±8 g on x, y and z axes. Raw acceleration data were downloaded from accelerometers in 1 s epochs and exported as .csv files using ActiLife software (ActiGraph, Pensacola, FL, USA). Raw data were then transformed into Euclidean Norm Minus One (ENMO) acceleration data using GGIR package (Van Hees, 2020) from R software Version 4.0.2 (www.r-project.org). Lastly, age appropriate cut-points were used classify ENMO accelerations time spent in MVPA (Crotti et al., 2020).

Teaching practices related with physical activity: SOFIT+

The following paragraph repeats information reported in Study 2 within the “Modified System for Observing Fitness Instruction Time SOFIT+” section (page 126).

PE video-recordings were analysed using the modified version of the System for Observing Fitness Instruction Time to measure teacher practices related with PA (SOFIT+) (Crotti et al., 2021a). SOFIT+ is a valid and reliable observation tool designed to classify multiple teacher practices related with children’s PA during PE (Crotti et al., 2021a). The teaching practices within the SOFIT+ are divided in 4 categories comprising *Lesson Context*, *Activity Context*, *Teacher Behaviours* and *Activity Management* and more information about the definition of each teaching practice can be found in supplementary material 5. Each SOFIT+ scan lasts 40 seconds divided in two 20 seconds phases each one comprising 10 seconds of observation and 10 seconds of recording (Crotti et al., 2021a). During the phase 1 of SOFIT+, *Lesson Context* and *Activity Context* teaching practices are assessed while during phase 2 *Teacher Behaviours* and *Activity Management* are assessed (Crotti et al., 2021a).

Details about observer training can be found in Study 2 the “Observer training and reliability” section (page 130)

Fidelity

Intervention fidelity in terms of Linear and Nonlinear pedagogy were assessed through the video analysis of recorded PE lessons using a checklist developed by the research team (Supplementary material 8) (Crotti et al., 2021b). The checklist comprised 9 items including 7 motor learning related items and 2 global items. Each item was rated using a 1 to 5 Likert sale where a value of 1 corresponded to the observation being in line with Linear Pedagogy while a value of 5 corresponded to the observation being in line with Nonlinear Pedagogy. Motor learning related items were assessed 4 times within each lesson (once for each quartile of the PE lessons) while global items were assessed only once per lesson observed. Two researchers that were not part of the research team independently coded the fidelity of the PE lessons following training. The training consisted in 1) reading specific literature concerning Linear and nonlinear pedagogy, 2) reading the fidelity checklist, 3) consulting the research team about doubts concerning the checklist, 4) independently coding 2 PE lessons, 5) consulting a pedagogy expert to check the coded lessons and clarify any doubts, 6) collaborating to assess 6 PE lessons, 7) independently assessing 6 lessons and then compare the results. The coders then assessed fidelity using the fidelity checklist within a total of 13 randomly selected PE lessons from Linear Pedagogy (5 lessons), Nonlinear Pedagogy (5 lessons) and Control group (3 lessons).

Data analysis

All data analysis was carried out using R Software (Version 4.0.2, www.r-project.org) and RStudio Software (Version 1.3.1056, www.rstudio.com). Multilevel models were used to analyse PA outcomes to account for MVPA data being nested within child, class and teacher. Multilevel models were fitted using "Lme4" package within R Software (Bates et al., 2020). To assess the association between pedagogy and MVPA during PE, two models were designed with children's MVPA during PE as the dependent variable: i) an unadjusted model including group (i.e. Linear pedagogy, Nonlinear pedagogy and control) as the independent variable with data nested by child (random intercept), and ii) a fully adjusted model including group (i.e. Linear pedagogy, Nonlinear pedagogy and control) as the independent variable and controlling for sex (Tanaka et al., 2018), age (Tanaka et al., 2018), lesson duration (Costa et al., 2016), lesson content (e.g. ball games) (Tanaka et al., 2018), lesson environment (i.e. indoor, outdoor) (McKenzie et al., 1995) with child id code, school and teacher included as nesting variables. Nesting by class was excluded as not leading to improved model fit or leading to overfitted models. IOTF BMI z-score, ethnicity and deprivation decile variables were excluded from the fully adjusted multilevel analysis as they did not improve model fit and led to issues with listwise deletion of missing data leading to the loss of 21 participants and 50 corresponding valid MVPA observations within the multilevel models (Table 13). The unadjusted and fully adjusted models were fitted using control group or Nonlinear pedagogy group as the 'group' reference category to evaluate whether Linear and Nonlinear interventions were associated with increased or decreased MVPA minutes or percentage of MVPA (MVPA%) compared to the control group and each other. Outliers were identified using absolute deviation around the median (Leys et al., 2013) and then removed from the dataset used for the final analysis.

It was not possible to use multilevel models to analyse the PA teaching practices data as the vast majority of teaching practices variables did not present a normal distribution of the residuals or led to overfitting problems within the multilevel models. PA teaching practices observations collected using SOFIT+ are count data, i.e. representing counts of events over a discrete time span (Hilbe, 2011, 2014; Friendly and Meyer, 2016). Therefore, Poisson and

Negative Binomial were initially considered for data analysis. The dispersion of the data was assessed using Dean's test (Dean, 1992). Given that all of the distributions of teaching practice data were over-dispersed, Negative binomials were used to evaluate differences in PA teaching practices between Linear pedagogy, Nonlinear pedagogy and control group within PE. In some cases (i.e. *Partner Activity* and *Small Sided Activity*), negative binomial models could not fit the data as an elevated proportion of zero counts were observed. In these cases, hurdle negative binomial models were employed to analyse teaching practices data (Hilbe, 2011, 2014; Friendly and Meyer, 2016; Blasco-Moreno et al., 2019). To account for differences in lesson duration an offset factor was included in Negative binomial and Hurdle Negative binomial models. The statistical model fit of count data models were assessed using McFadden's pseudo R squared (Smith and McKenna, 2013). Due to the relatively small number of lessons observed within each group and for each PE deliverer, it was not possible to add covariates to the Negative binomial models as it was leading to overfitting (models failing to converge).

Results

Participants in the current study (n = 162; 53% girls) presented a mean age of 6.0 (Standard Deviation (SD) = 0.3) years, 49% were white British, and 84% of the children lived in areas ranked as within the most deprived tertile for deprivation in the England. IOTF BMI z-scores were calculated for the 146 children and, based on IOTF thresholds (Cole and Lobstein, 2012), 24% of children were overweight or obese.

Table 13. Participants' descriptive data by group

	Linear Pedagogy (n=55)		Nonlinear Pedagogy (n=65)		Control (n=42)	
	Mean (SD) or %	**Missing data**	**Mean (SD) or %**	**Missing data**	**Mean (SD) or %**	**Missing data**
Decimal Age (years)	6.0 (0.3)	0	5.9 (0.3)	0	5.9 (0.3)	0
Girls	56%	0	49%	0	55%	0
White British	62%	2	56%	2	24%	0
Living within the 30%	93%	0	71%	0	95%	1
IOTF SDS BMI	0.4 (1.2)	3	0.5 (1.1)	4	0.2 (1.1)	9
IOTF SDS BMI classification						
Thinness grade 3	0%		0%		0%	
Thinness grade 2	4%		2%		0%	
Thinness grade 1	2%		3%		6%	
Healthy weight	67%		75%		67%	
Overweight	25%		8%		21%	
Obese	2%		11%		6%	

IOTF SDS BMI: standardised BMI z-scores following international Obesity task force classification.

Each of the 15 participating classes were observed 3 times during PE. In total, 44 PE lessons were recorded as two classes within the control group did one PE lesson together. Audio was not recorded in one of the control PE lessons because of technical problems. 43 PE lessons were assessed using SOFIT+ and combined with children's corresponding PA data for analyses. PA levels during PE were assessed in 42 (23 girls) children from the Control group, 65 (32 girls) children from the Nonlinear Pedagogy group and 55 (31 girls) children from the Linear pedagogy group. Due to child absence from school, 114 (56 girls) children were assessed over 3 lessons, 32 (24 girls) children were assessed over 2 lessons, and 16 (6 girls) children were assessed over 1 lesson.

Pedagogic fidelity

Pedagogic Fidelity scores were reported in Table 14. Nonlinear pedagogy average intervention fidelity scores ranged from 3.95 (SD = 0.78) to 5 (SD = 0.00), Linear pedagogy intervention average fidelity scores were all lower than 1.77 (0.94), while control group average scores were comprised between 1.44 (SD = 0.97) and 2.50 (SD = 0.54) (Crotti et al., 2021b). Fidelity scores of 1 and 2 on the Likert scale correspond to the observation being more in line with Linear Pedagogy and scores of 4 and 5 correspond to the observation being in line with Nonlinear Pedagogy. Therefore, the fidelity observations indicated that Linear and Nonlinear interventions were delivered in line with their respective pedagogical principles. The control group presented fidelity scores indicated closer alignment with Linear pedagogy principles.

Table 14. Pedagogical fidelity checklist results

	Category							**Global**	
	Category Mean (SD)							**Global Mean (SD)**	
	1	**2**	**3**	**4**	**5**	**6**	**7**	**1**	**2**
Nonlinear	5.00 (0.00)	5.00 (0.00)	4.90 (0.28)	3.95 (0.78)	4.05 (0.77)	4.73 (0.41)	4.58 (0.43)	5.00 (0.00)	5.00 (0.00)
Linear	1.40 (0.64)	1.48 (0.85)	1.20 (0.41)	1.77 (0.94)	1.20 (0.41)	1.63 (0.88)	1.63 (0.75)	1.40 (0.74)	1.33 (0.82)
Control	2.10 (0.83)	2.15 (1.04)	2.19 (0.88)	1.44 (0.97)	2.33 (0.87)	2.21 (0.75)	2.50 (0.54)	2.00 (1.08)	1.92 (1.11)

SD: standard deviation

Children's moderate to vigorous physical activity during physical education lessons

The mean and standard deviation for MVPA minutes, MVPA% and number of children spending 50% of PE time in MVPA can be found in Table 15. On average, children in the different groups engaged in MVPA during PE lessons for between 9.1 and 11.9 minutes, with the proportion of lesson time spent in MVPA ranging from 29.1% and 38.4%. The percentage of children engaging in MVPA over at least 50% of PE time ranged from 5.3% to 14.4% (Figure 9).

Table 15. Physical activity outcomes derived from accelerometers and teacher practices assessed using SOFIT+

	Linear Pedagogy		Nonlinear Pedagogy		Control	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**
Physical activity during PE						
MVPA (minutes)	11.4	3.7	11.9	4.3	9.1	4.0
MVPA (%)	35.1	10.1	38.4	10.9	29.1	11.4
Children spending ≥50% of PE time in MVPA (%)	9.0	13.1	14.4	17.9	5.3	16.6
SOFIT+ Lesson Context						
Management (%) -	23.9	7.7	22.2	9.2	40.2	17.2
Knowledge (%) -	25.5	12.6	14.9	9.9	22.5	8.3
Motor Content (%) +	50.6	10.5	62.8	14.7	37.3	15.1
Fitness (%) +	2.7	4.9	0.2	0.9	2	4.8
Skill Practice (%) +	45.1	9.7	0.6	2	17.2	22.6
Game Play (%) +	2.7	4.3	21.2	34.8	18.1	12.7
Free Play (%) -	0	0	0	0	0	0
Discovery Practice (%) +	0.1	0.4	40.8	27.8	0	0
SOFIT+ Activity Context						
Individual Activity (%) +	25.9	16.1	24.3	20.3	4.7	12.8
Partner Activity (%) +	14.8	16.7	13.6	25.1	14.9	21.6
Small Sided Activity (%) +	4.5	8.6	3.7	8.3	3.8	9.3
Large Sided Activity (%) -	0	0	15.9	32.9	2.2	5.5
Whole Class Activity (%) +	5.4	6.2	5.3	10.6	11.7	12.6
Waiting Activity (%) -	9.5	11.1	0.3	0.8	7.9	13.2
Elimination Activity (%) -	0	0	0	0	3.5	8.6
Girls Only Activity (%) -	0	0	0	0	0	0
Children Off Task (%) -	6.8	7.1	6.6	6.2	2	2.7
SOFIT+ Teaching Behaviours						
Supervises (%) +	24.3	8	16.6	11.9	20.7	15.1
Instructs Single Child (%) -	17.7	11.3	31.7	14.7	27.1	12.9
Instructs Group (%) -	6.4	6.7	24.7	17.8	7.7	7.8
Instructs Class (%) -	41	14.1	26.5	13.7	38.5	11.2
Promotes PA (%) +	0	0	0.2	0.6	0.6	1.6
PA as Punishment (%) +	0	0	0	0	0	0
Withholding PA (%) -	0.1	0.4	1.4	5.5	0.9	3.3
PA Engaged (%) +	8	6	0	0	3	4.4
Off Task (%) -	2.6	2.8	0.5	0.9	3	2.6
SOFIT+ Activity Management						
Signalling (%) -	5.9	4.5	4.7	4.6	3.1	2.6
Retrieving equipment M* (%) -	0	0	0	0	0	0
Retrieving equipment O* (%) -	1.3	2.1	0.3	0.7	1.7	2.6
Interruption Public (%) -	3.8	2.4	4.7	3.7	5.6	5.6
Interruption Private (%) -	1.5	1.8	6	4.5	4.6	4.2

SD: standard deviation; **PE:** physical education; **M*:** multiple points; **O*:** one point; **+ :** the teaching practice was theorised to foster children's moderate to vigorous physical activity; **- :** the teacher practice was theorised to reduce children's moderate to vigorous physical activity.

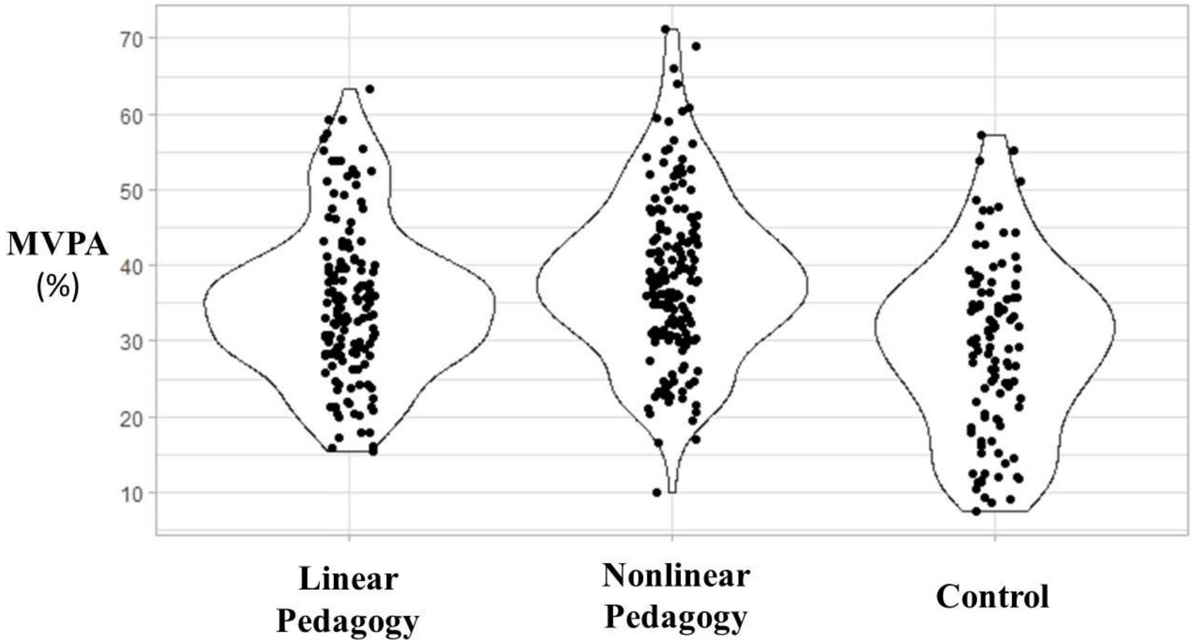

Figure 9. Percentage of time spent in moderate to vigorous physical activity in physical education

Figure 9 presents a violin density plots (shapes delimited by line) and dot plots concerning percentage of time spent in MVPA during PE; Each dot represents a single unadjusted MVPA measurement in one child during one lesson and dots were randomly scattered on the horizontal axis.

Associations between pedagogy and children's physical activity

Results from the multilevel model analyses evaluating the associations between pedagogy group and children's average time spent in MVPA minutes during PE are reported in Table 16, while results concerning MVPA% during PE can be found in Table 17. Both Linear and Nonlinear interventions were associated with significantly higher minutes in MVPA and MVPA% percentage compared to the control group within the unadjusted models. However, within the fully adjusted models, Linear and Nonlinear pedagogy were not associated with increased MVPA or MVPA% compared to control group. Furthermore, Linear and Nonlinear pedagogy were not associated higher MVPA or MVPA% compared to each other both in the unadjusted and fully adjusted model.

Table 16. Association between pedagogy group and children's minutes of moderate to vigorous physical activity during physical education

	Unadjusted model			Fully adjusted model		
Predictors	**Estimate**	**CI**	**p-value**	**Estimate**	**CI**	**p-value**
Group [Nonlinear vs Control]	2.58	1.57 – 3.59	<0.001	1.69	-1.81 – 5.19	0.343
Group [Linear vs Control]	2.36	1.33 – 3.40	<0.001	0.88	-2.95 – 4.71	0.652
Group [Linear vs Nonlinear]	-0.22	-1.14 – 0.71	0.648	-1.69	-5.19 – 1.81	0.343
Sex				-1.12	-1.74 – -0.50	<0.001
Decimal Age				1.03	-0.06 – 2.12	0.065
Lesson Location				2.21	0.35 – 4.07	0.02
Lesson content [Ball Games]				2.5	1.43 – 3.56	<0.001
Lesson content [Dance]				0.95	-1.64 – 3.53	0.473
Lesson content [Gymnastic]				2.45	-0.29 – 5.18	0.079
Lesson Duration				0.26	0.21 – 0.32	<0.001
σ^2	12.75			4.78		
τ_{00}/ICC Participants	1.63			1.80/0.16		
τ_{00}/ICC Schools				0.76/0.07		
τ_{00}/ICC Teachers				4.00/0.35		
ICC random factors	0.11			0.58		
Participants	162			162		
Schools				9		
Teachers				9		
PA Observations	416			416		
Marginal R^2 / Conditional R^2	0.076 / 0.181			0.408 / 0.751		

σ^2: Intercept variance; **τ_{00}**: Random factor variance; **ICC:** intraclass correlation index; **PA:** physical activity.

Table 17. Association between pedagogy group and children's percentage of moderate to vigorous physical activity during physical education

	Unadjusted model			Fully adjusted model		
Predictors	**Estimate**	**CI**	**p-value**	**Estimate**	**CI**	**p-value**
Group [Nonlinear vs Control]	8.68	5.84 – 11.51	<0.001	7.91	-1.74 – 17.57	0.108
Group [Linear vs Control]	6.15	3.25 – 9.06	<0.001	6.14	-4.59 – 16.87	0.262
Group [Linear vs Nonlinear]	-2.52	-5.12 – 0.08	0.057	-1.77	-7.72 – 4.18	0.56
Sex				-3.6	-5.55 – -1.65	<0.001
Decimal Age				2.99	-0.47 – 6.45	0.09
Lesson Location				3.85	-1.90 – 9.61	0.19
Lesson content [Ball Games]				7.53	4.18 – 10.89	<0.001
Lesson content [Dance]				-1.3	-9.35 – 6.75	0.752
Lesson content [Gymnastic]				5.94	-2.53 – 14.41	0.17
Lesson Duration				-0.35	-0.52 – -0.17	<0.001
σ^2	89.19			47.65		
τ_{00}/ICC Participants	17.03			18.16/0.18		
τ_{00}/ICC Schools				3.83/0.04		
τ_{00}/ICC Teachers				29.43/0.30		
ICC random factors	0.16			0.52		
Participants	162			162		
Schools				9		
Teachers				9		
PA Observations	416			416		
Marginal R^2 / Conditional R^2	0.100 / 0.245			0.267 / 0.648		

σ^2: Intercept variance; **τ_{00}**: Random factor variance; **ICC:** intraclass correlation index; **PA:** physical activity.

Within the fully adjusted models, sex was significantly and negatively associated with both MVPA minutes and MVPA% meaning that girls were generally less active than boys during PE. Age was not significantly associated with MVPA minutes and MVPA%, while PE lessons delivered outdoors were associated with higher MVPA minutes in children compared to lessons indoors. Ball games lesson content was found to be associated with higher MVPA minutes and MVPA% compared to locomotor activities (reference category) while Gymnastic was associated with higher levels of MVPA minutes compared to locomotor activities. Lesson duration was significantly and positively associated with MVPA minutes and negatively associated with MVPA%.

Teaching practices associated with physical activity

The characteristics of PE lessons in terms of lesson content, lesson duration lesson location and teacher delivery are reported in Table 18. PE lessons lasted 32:07 min:s on average (SD = 06:14 min:s) and 14 out of 44 lessons took place outdoors. The observed PE lessons were delivered by 4 teachers and external sports coaches in the control group while 5 trained sports coaches delivered the observed PE lessons between interventions as reported in Table 18. Due to the restricted availability of deliverers during the intervention period, the two coaches recruited from the research team delivered both Nonlinear pedagogy and Linear pedagogy as they were trained in both pedagogical approaches (Table 18).

Table 18. Lesson characteristics.

	Linear Pedagogy	**Nonlinear Pedagogy**	**Control**
Lesson duration mean ± SD (minutes)	34.2 ± 6.6	30.8± 6.8	31.2 ± 5.0
Lessons observed	15	15	13
Locomotor activities			8
Gymnastic	5	5	
Dance	5	5	
Ball games	5	5	5
Number of Physical education lesson by deliverer			
Deliverer 1			3
Deliverer 2			3
Deliverer 3			6
Deliverer 4			1
Deliverer 5		3	
Deliverer 6		7	
Deliverer 7	4	1	
Deliverer 8	2	4	
Deliverer 9	9		

The mean and standard deviation concerning teaching practices divided by group can be found in table 15. Furthermore, Table 15 indicates whether the teacher practice was theorised to foster or to hinder children's engagement in MVPA during PE (Weaver et al., 2016; Fairclough et al., 2018; Crotti et al., 2021a). *Motor Content* was more frequently observed compared to *Knowledge* and *Management* in intervention groups while in the Control group the average time spent in *Management* was higher than the time spent in *Knowledge* and *Motor Content*. When considering *Motor Content* variables, *Skill Practice* (45.1%) was the most frequently observed teaching practice in the Linear pedagogy group while *Discovery Practice* presented the highest mean percentage (40.8%) in Nonlinear pedagogy group and lastly *Game Play* involved the highest men percentage (18.1%) within the Control group. As for *Activity Context*, *Individual Activity* was prioritised in both the intervention groups (25.9% and 24.3% for Linear and Nonlinear group respectively), while *Partner Activity* presented the highest mean percentage (14.9%) in the Control group. As concerns *Teaching Behaviours* variables, *Instructs Class* was the most frequently observed teaching practice in both Linear pedagogy (41%) and Control group (38.5%) while *Instructs Single Child* (31.7%) presented the highest mean percentage in Nonlinear group. As for *Activity Management* variables, *Signalling* was the most observed in Linear (5.9%) and Nonlinear pedagogy (4.7%) groups while *Interruption Public* (5.6%) was the most observed in the control group. SOFIT+ teaching practice variables comprising *Free play*, *Girls Only activity*, *PA as Punishment* and *Retrieving equipment from multiple access points* were never observed during the PE lessons (Table 16), while *PA Engaged* and *Withholding PA* teaching practices were only observed in 3 and 6 lessons, respectively. Therefore, a statistical analysis could not be completed for these variables.

The results from the analysis of teaching practices can be found in Table 19. As regards *Lesson Context* variables, Linear Pedagogy presented higher incidence of *Motor Content* and *Skill Practice* as well as lower incidence of *Management* and *Game Play* compared to the control group. Nonlinear pedagogy group presented higher incidence of *Motor Content* and *Discovery Practice* (Table 19) together with lower incidence of *Knowledge, Management, Skill Practice* compared to the control group. Additionally, Linear pedagogy group involved an increased incidence of *Knowledge* and *Skill Practice* while it included lower *Motor Content, Game Play* and *Discovery Practice* (Table 19) compared to Nonlinear pedagogy group.

For *Activity Context* variables, Linear Pedagogy presented higher incidence of *Individual Activity* and *Children Off Task* as well as lower incidence of *Elimination Activity* (Table 19) compared to the control group. Furthermore, Nonlinear pedagogy group presented higher incidence of *Individual Activity* and *Children Off Task* together with lower incidence of *Waiting Activity* and *Elimination Activity* compared to the control group. Lastly, Linear pedagogy group involved an increased incidence of *Waiting Activity* compared to Nonlinear pedagogy group.

For Teaching Behaviours variables, Linear Pedagogy presented higher incidence of *PA Engaged* and lower incidence of *Instructs Single Child* compared to the control group. Furthermore, Nonlinear pedagogy group presented higher incidence of *Instructs Group* as well as lower incidence of *Instructs Class, PA Engaged* (Table 19) and *Off Task* compared to the control group. Additionally, Linear pedagogy group involved increased *Instructs Class*, *PA Engaged* (Table 19) and *Off Task* together with lower *Instructs Single Child* and *Instructs Group* compared to Nonlinear pedagogy group.

As regards *Activity Management* Variables, Linear pedagogy presented lower incidence of *Interruption Private* compared to Control group and Nonlinear pedagogy group while no other significant differences were found.

Table 19. Difference in teaching practices between the interventions and control group

Teaching practice	Linear vs Control Incidence	Std. Error	p-value	Nonlinear Vs Control Incidence	Std. Error	p-value	Linear vs Nonlinear Incidence	Std. Error	p-value	McFadden
Lesson Content										
Knowledge	1.14	0.23	0.513	**0.66**	**0.14**	**0.049**	**1.74**	**0.36**	**0.007**	0.039
Management	**0.59**	**0.08**	**<0.001**	**0.54**	**0.08**	**<0.001**	1.08	0.16	0.609	0.065
Motor Content	**1.36**	**0.15**	**0.005**	**1.7**	**0.18**	**<0.001**	**0.8**	**0.08**	**0.020**	0.114
Fitness	1.35	1.37	0.769	0.13	0.17	0.104	10.06	12.04	0.054	0.037
Skill Practice	**2.62**	**1.18**	**0.033**	**0.03**	**0.02**	**<0.001**	**76.29**	**49.79**	**<0.001**	0.725
Game Play	**0.15**	**0.1**	**0.006**	1.18	0.78	0.806	**0.13**	**0.09**	**0.002**	0.042
Activity context										
Individual Activity	**5.81**	**3.02**	**0.001**	**5.43**	**2.83**	**0.001**	1.07	0.51	0.886	0.532
Partner Activity	0.71	0.29	0.397	0.75	0.32	0.497	0.94	0.35	0.877	0.020
Small Sided Activity	0.68	0.31	0.400	0.53	0.25	0.184	1.29	0.53	0.538	0.028
Whole Class Activity	0.45	0.26	0.162	0.46	0.26	0.175	0.98	0.56	0.969	0.012
Waiting Activity	1.19	0.93	0.820	**0.04**	**0.04**	**0.002**	**32.08**	**32.66**	**0.001**	0.066
Children Off Task	**3.74**	**1.91**	**0.010**	**3.48**	**1.78**	**0.015**	1.08	0.46	0.866	0.054
Teaching Practices										
Supervises	1.16	0.25	0.483	0.79	0.18	0.292	1.48	0.32	0.068	0.029
Instructs Single Child	**0.66**	**0.13**	**0.038**	1.17	0.22	0.404	**0.57**	**0.11**	**0.003**	0.040
Instructs Group	0.86	0.31	0.668	**3.22**	**1.11**	**0.001**	**0.27**	**0.09**	**<0.001**	0.080
Instructs Class	1.06	0.16	0.694	**0.68**	**0.11**	**0.015**	**1.56**	**0.24**	**0.003**	0.032
PA Engaged	**2.62**	**1.13**	**0.025**							0.034
Off Task	0.92	0.3	0.791	**0.18**	**0.1**	**0.003**	**4.95**	**2.74**	**0.004**	0.150
Activity Management										
Signalling	1.86	0.65	0.077	1.47	0.53	0.287	1.26	0.4	0.457	0.015
Retrieving equipment O	0.83	0.53	0.767	0.17	0.16	0.052	4.81	4.31	0.080	0.076
Interruption Public	0.7	0.23	0.285	0.85	0.28	0.614	0.82	0.28	0.563	-0.010
Interruption Private	**0.31**	**0.12**	**0.003**	1.24	0.39	0.484	**0.25**	**0.1**	**<0.001**	0.076

Significant results (p-value<0.05) were highlighted using bold font; **O:** One access point

Discussion

This study aimed to evaluate and compare children's MVPA and teaching practices associated with MVPA during primary school PE within different PE pedagogical approaches (Linear and Nonlinear) and current practice in PE. The results suggest that primary PE interventions focusing on movement competence guided by Linear pedagogy and Nonlinear pedagogy were not associated with different levels of children's MVPA during PE when compared to current practice in PE. Other factors were associated with children's MVPA time and MVPA% in PE including the sex of the participants (boys), lesson duration (longer), lesson location (outdoors), lesson content (ball skills, gymnastic, dance), while the teacher providing the lesson also explained a high proportion of MVPA variance. Furthermore, only a small proportion of children engaged in MVPA for at least 50% of PE time both in the intervention (Linear pedagogy: 9.0%, Nonlinear Pedagogy: 14.4%) and control groups (5.3%) (Figure 9). As for teaching practices during PE, a higher incidence of PA promoting teaching practices (e.g. *Motor Content*, *Skill Practice*, *Discovery Practice*, *Individual PA*, *PA Engaged*) and lower incidence of PA decreasing teaching practices (e.g. *Knowledge*, *Management*, *Instructs Class*, *Off Task*) were found in PE lessons guided by Linear and Nonlinear pedagogical approaches. Lastly, Linear and Nonlinear interventions were delivered maintaining fidelity to the Linear and Nonlinear pedagogical principles respectively. The results obtained in this study extend knowledge about MVPA promotion in early primary PE under different pedagogies.

Increasing physical activity in physical education

As shown in Figure 9, the majority of children's MVPA levels within both intervention and control groups did not reach the recommended MVPA engagement of 50% of the PE lesson duration (Pate et al., 2006; AAHPERD, 2013; afPE, 2020). This is in line with the vast majority of studies assessing MVPA in PE using accelerometers and observation tools, even when those

PE lessons were led by specialists whose aim was to promote high MVPA during PE (McKenzie et al., 1993, 1995, 1997; Telford et al., 2016). This suggests that high quality PE targeting other learning outcomes such as movement competence does not necessarily lead to a specific threshold of MVPA engagement. Therefore, future studies should seek to identify additional ways to promote PA whilst providing rich movement competence learning experiences for children.

This study was the first to evaluate the association between Linear pedagogy and Nonlinear pedagogy with children's MVPA and to compare PA engagement in these pedagogies with current practice in PE in primary schools. The results from this study suggest that Linear pedagogy or Nonlinear pedagogy was not a significant predictor of MVPA engagement in PE. The lack of an association between participation in the motor learning pedagogy interventions and children's MVPA in PE could be due to the intervention being designed to improve movement competence in children rather than MVPA (Rudd et al., 2020a). Indeed, the vast majority of previous studies where higher levels of MVPA during PE were observed in the intervention group compared to the control condition included specific strategies to improve MVPA during PE (e.g. teacher training to deliver specific MVPA promoting PE content) and reported MVPA engagement during PE as being the primary outcome of the intervention (McKenzie et al., 1996; Sallis et al., 1997; Coleman et al., 2005; Fairclough and Stratton, 2005; Logan et al., 2015; Powell et al., 2016, 2020; Telford et al., 2016; Weaver et al., 2017, 2018a). However, results from many of these previous studies should be interpreted with caution as, unlike the present study, they did not account for factors associated with MVPA in PE such as children's sex, age and BMI, lesson content, lesson location and lesson duration (McKenzie et al., 1996; Sallis et al., 1997; Coleman et al., 2005; Robinson et al., 2015; Powell et al., 2016, 2020) and/or studies did not account for children being nested within schools, classes or teacher within their statistical analyses (Powell et al., 2016, 2020).

The Partnerships for Active Children in Elementary Schools (PACES) study is an example of PE intervention focusing on MVPA promotion in primary school PE (6-9 years old children) that was effective in increasing MVPA in PE and employed similar methods to the present study (Weaver et al., 2017). The PACES intervention involved a teacher training element aimed at modifying teaching practices to increase children's MVPA in PE (Weaver et al., 2017) based on the "LET US Play" principles comprising: elimination, team size, uninvolved children and space, equipment and rules (Weaver et al., 2013, 2017). The PACES intervention successfully decreased children being off task (time when one or more students are not engaged in the task proposed by the teacher) and increased verbal promotion of PA as well as small-sided activities during PE (Weaver et al., 2017). As a result, the PACES intervention reported an increase in children's MVPA percentage in girls (from 22.7% to 26.6%) and boys (from 33.2% to 39.0%) from baseline values before the intervention (Weaver et al., 2017). The Linear and Nonlinear pedagogy interventions reported in this study presented similar or higher MVPA% (35.1% and 38.4%) compared to the PACES intervention study (Weaver et al., 2017). However, Linear and Nonlinear pedagogy interventions presented lower percentages of small-sided activities (3.7%-4.5%) and verbal PA promotion (0-0.2%) as well as higher percentages of children being off task (6.6%-6.8%) compared to PACES study intervention (*Small Sided Activity*: 9.3%; Teacher verbally *Promotes PA* 13.5%; *Children off task* 2.0%) (Weaver et al., 2017). Therefore, future Linear and Nonlinear pedagogy interventions aiming to engage children in MVPA over more than 50% of the PE lessons could consider targeting the increase in small-sided activities, verbal PA promotion together with the decrease of children being off task.

Weaver et al. (2018) conducted a follow-up study that also involved teacher training in the "LET US play" principles. Using similar methods (SOFIT+ and accelerometers) to the present study, the authors reported significant improvements in 6-10 year-old children MVPA during PE (from 6.6 to 7.9 minutes in girls, from 9.1 to 11.1 minutes in boys) (Weaver et al., 2018b). The intervention was successful at increasing MVPA promoting practices such as time in "*Motor Content*" while it reduced MVPA decreasing teaching practices such as "*Knowledge* (instruction time)", and "*Waiting Activity*" (Weaver et al., 2018b). Compared to the study by Weaver et al. (2018) (Knowledge 1.9-6.2%, *Management*, *Motor Content* 69.1-77.5%) both intervention and control groups in this study presented on average higher *Knowledge* time (14.9-25.5%) and lower *Motor Content* time (37.3-62.8%) while similar *Management* time was observed in Linear and Nonlinear interventions (22.2-23.9%) and in Weaver et al. (2018) study (20.6-24.6%) (Weaver et al., 2018b). These finding suggest that focusing on decreasing *Knowledge* time and increasing *Motor Content* time could be an effective and feasible strategy to foster children's MVPA engagement in future Linear and Nonlinear Pedagogy interventions. As concerns waiting activities, lower percentages were found in this study within Linear (9.5%) and Nonlinear (0.3%) interventions compared to Weaver et al. (2018) intervention (11.1%) (Weaver et al., 2018b). However, Linear Intervention presented significantly higher percentages of *Waiting Activity* compared to Nonlinear pedagogy intervention, suggesting that future Linear pedagogy interventions should focus on decreasing *Waiting Activity* practices to increase MVPA in children.

A further study aiming to increase MVPA in PE evaluated the "SHARP" intervention, which included teacher training to embed specific principles in PE comprising: stretching whilst moving, high repetition of motor skills, designing inclusive activities and reducing sitting and standing time (Powell et al., 2016). The SHARP intervention involved 7-9 years old children and included SOFIT to measure MVPA and teaching practices (Powell et al., 2016).

The SHARP intervention reported a significant increase in MVPA together with increased time in teaching practices such as "*Skill Practice*" and "in class PA promotion" within the intervention group compared to the control group (Powell et al., 2016). The increase in *Skill Practice* observed in the SHARP intervention could be associated with the SHARP principle concerning "high repetition of motor skills" that is also a key principle within the Linear Pedagogical intervention delivered in this study suggesting that practicing movement skills can significantly contribute to MVPA in PE (Powell et al., 2016; Sacko et al., 2019). Furthermore, the high percentages of verbal PA promotion within the SHARP (42.3%) intervention compared to the ones observed in this study (0-0.2%) confirms that future Linear and Nonlinear interventions should focus on improving verbal PA promotion during PE delivery as a strategy to improve MVPA in PE (Powell et al., 2016).

Factors associated with children's physical activity in physical education

The teacher delivering PE explained a high proportion of variance in the fully adjusted models examining children's MVPA minutes (ICC = 0.35) and MVPA% (ICC = 0.30) (Hoffman, 2019) (Tables 16-17), suggesting that teachers are an important predictor of activity levels. More specifically, the high proportion of variance explained by the teachers in our models suggests that children doing PE with the same teacher reached similar levels of MVPA engagement during PA (Park and Lake, 2005; Hoffman, 2019). In other words, some teachers were more effective in promoting MVPA in PE than others irrespective of them being in the intervention or in the control group. This could be due to the teacher expertise and their knowledge and experience about strategies to engage children in high levels of PA (McKenzie et al., 1993, 1995, 1997; Telford et al., 2016). In line with this, the MVPA and MVPA% during PE within the control group were delivered by a class teacher, two coaches (sports coaches hired from external sport coaching organisations), and a PE specialist teacher. This potentially explains why the mean observed in the control group (9.1 min, 29.1%,) was similar or higher than previous studies where PE was provided by generalist class teacher where mean MVPA during PE ranged from 3.5 min to 10.8 min and MVPA mean percentage ranged 9.5% to 29.7% (Nettlefold et al., 2011; Wood and Hall, 2015; Tanaka et al., 2018). Interestingly, the mean MVPA percentages observed in the Linear (35.1%), and Nonlinear (38.4%) intervention groups were similar to the proportion of children's MVPA during PE observed in a study involving specialised PE teachers, with 36.7% of the lessons spent in MVPA (Costa et al., 2016). This might be due to the intervention deliverers in the present study having experience in PE delivery in primary school children and to the intervention delivery not including generalist classroom teachers or it might be due to the interventions content (McKenzie et al., 1993, 1995, 1997; Telford et al., 2016).

Consistent with previous literature, it was found that MVPA during PE was associated with several factors with girls presenting lower levels of MVPA and MVPA% compared with boys (Tanaka et al., 2018), longer lessons leading to higher minutes spent in MVPA but lower MVPA% (Costa et al., 2016), lesson content being associated with MVPA and MVPA% where ball games activities led to the highest MVPA and MVPA% engagement (Tanaka et al., 2018), and lastly, outdoor activities being associated with higher levels of MVPA compared to indoor ones when factoring teachers into the models (Kwon et al., 2020). In view of these results, researchers and practitioners should account for these factors when designing interventions to foster MVPA in PE. In particular, key aspects to consider should be: 1) finding strategies to engage girls in MVPA, for example, proposing activities that are meaningful and enjoyable for them (Peral-Suárez et al., 2020); 2) including relevant high intensity game activities with the PE lesson (Wood and Hall, 2015; Tanaka et al., 2018); 3) using outdoor spaces when the weather conditions allow it as outdoors PE is associated with higher MVPA levels in children compared to indoors PE (McKenzie et al., 1995), and 4) finding strategies to maximise lesson duration (e.g. making sure that the lesson starts and ends as established by the school curriculum) (Costa et al., 2016).

Teaching practices in pedagogies underpinned by movement learning theories

The SOFIT+ data provided valuable information about the characteristics of Linear and Nonlinear pedagogy approaches in terms of teaching practices, which can be used to improve PE delivery to promote MVPA engagement in the future.

In agreement with the Linear pedagogy principles stating that children should practice skills within drills before applying them to game situations, Linear pedagogy intervention presented higher *Skill Practice* and less *Game Play* compared to the Nonlinear Pedagogy and control groups, as well as higher *Individual Activity* compared to the control group (Fitts and Posner, 1967; Metzler, 2017; Crotti et al., 2021b). Furthermore, Linear pedagogy intervention presented a higher proportion of *Skill Practice* and *Instructs Single Child* compared with other groups, and a higher proportion of Instructing the class compared to the Nonlinear group in line with teacher-centred PE approaches (Mosston and Ashworth, 2008; Goodyear and Dudley, 2015). Compared to the control group, the Linear pedagogy Intervention involved a higher proportion of time spent in *Motor Content* and teacher PA engagement that are associated with increased MVPA levels during PE together with less time spent in *Management* activities and *Elimination Activity* that are associated with decreased MVPA. This suggests that Linear pedagogy could help achieve increased MVPA in PE and increase time for movement competence practice (Weaver et al., 2016; Fairclough et al., 2018; Crotti et al., 2021a). However, *Game Play* was found to be associated with the highest MVPA engagement in PE compared to other type of *Lesson Contexts* and was observed less frequently in Linear intervention compared to control group (Weaver et al., 2016; Tanaka et al., 2018; Crotti et al., 2021a). Furthermore, a higher percentage of *Children Off Task* was observed in Linear pedagogy group compared to control group. Therefore, future interventions guided by Linear pedagogy should consider increasing the proportion of time children spend in *Game Play* and find strategies to decrease *Children Off Task* within PE lessons to improve MVPA engagement.

In accordance with Nonlinear pedagogy being a child-centred PE approach and the guiding principle that learning should take place through perception action coupling explorative processes, the Nonlinear pedagogy intervention presented a lower proportion of time in *Knowledge* and *Instructs Class* compared to other groups and it was practically the only intervention group where *Discovery Practice* was observed while *Skill Practice* was not (Mosston and Ashworth, 2008; Chow and Atencio, 2014; Goodyear and Dudley, 2015; Correia et al., 2019). Furthermore, the lack of *Skill Practice* and the high proportion of *Game Play* is in line with the Nonlinear pedagogy principle of learning movement skills in a representative design (Chow and Atencio, 2014; Correia et al., 2019). The Nonlinear intervention presented a higher proportion of MVPA promoting teaching practices (i.e. *Motor Content*) and a lower proportion of MVPA decreasing teaching practices (i.e. *Knowledge*, *Management*, *Waiting Activity*, *Elimination Activity*, *Instructs Class* and teacher being *Off Task*) compared to the control group, suggesting that Nonlinear pedagogy could help achieve increased MVPA in PE and increase time for movement competence practice (Weaver et al., 2016; Fairclough et al., 2018; Crotti et al., 2021a). However, compared to the control group, Nonlinear pedagogy intervention presented a higher proportion of *Children Off Task* (associated with decreased MVPA in PE) while teachers never engaged in PA with students, which is considered an MVPA promoting teaching practice. Therefore, future Nonlinear intervention should take in consideration aspects to decrease *Children Off Task* and for teacher to participate in PE as an active constraint to promote MVPA engagement.

Lastly, both Linear and Nonlinear intervention presented none or almost no verbal promotion of PA engagement that might be due to these approaches not being focused on increasing MVPA engagement suggesting that this aspect could be improved in future interventions.

Strengths and limitations

This study included several strengths comprising being the first study to analyse the association between Linear and Nonlinear pedagogy approaches in PE with children's MVPA in PE, and the first study to use accelerometry to report MVPA during PE among 5-6 years old children. A further strength was the simultaneous assessment of children's MVPA together with the observations of MVPA teaching practices by PE teachers within the same lessons. A further strength was that multilevel models accounting for different variables associated with children's MVPA were compared and that the models accounted for the nested structure of the data (i.e. observations being nested in children and children being nested in schools), while teaching practices data were analysed with the most appropriate models for count data. However, this study also has some limitations such as MVPA only being assessed in 50% of the children in the PE class that agreed to take part in the research project. Furthermore, due to the relatively small amount of teaching practices data collected per group and per PE deliverer, it was not possible to account for factors such as teacher and lesson content in the teaching practice analysis and some teaching practices variables were only observed a few times, making it impossible to run a statistical analysis. Lastly, one PE lesson was excluded because of technical problems in the video recording of the lesson.

Future directions

Future research could evaluate the implementation of movement learning pedagogical approaches in older children or adolescents to see if similar results are obtained compared to this study. Furthermore, future research could include qualitative methods to examine children's PA experiences during PE under different pedagogical approaches and how experiences in PE within movement learning pedagogical approaches could affect young people willingness to maintain high engagement in PE (Ennis, 2017). Future research assessing teaching practices associated with MVPA in PE should consider assessing a higher number of PE lessons per group and PE deliverers compared to this study with a particular attention to observe an adequate sample of PE lessons for each PE deliverer to collect teaching practices data allowing the design of complex statistical analysis models. Lastly, research could evaluate whether classroom teacher professional training to deliver different pedagogies in PE as well as improving teaching practices associated with MVPA in PE might positively enhance their capacity and willingness to promote MVPA in PE sessions to improve movement competence.

Conclusion

Compared to current practice in PE, interventions based on Linear and Nonlinear pedagogy were not associated with increased children's MVPA, but they included a higher incidence of MVPA promoting teaching practices (e.g. *Motor content*, *Skill Practice*, *Discovery Practice*). Nevertheless, the findings suggest that utilising Linear and Nonlinear pedagogies in PE could potentially improve movement competences in young children without compromising children's PA levels. Given that PE deliverers were the main predictor of MVPA in PE in this study, future interventions should focus on improving the pedagogic knowledge and skills of PE deliverers about increasing children's MVPA. This paper provides valuable information about how teaching practices within different pedagogical approaches affect PA in PE and proposes teaching practices that should be targeted to improve MVPA in PE. These findings can be used to help practitioners and researchers in designing future PE or coaching interventions based on Linear or Nonlinear pedagogies and/or maximizing MVPA engagement in PE.

Chapter 6: Study 4

Effect of linear and nonlinear pedagogy physical education interventions on children's physical activity: a cluster randomized controlled trial (SAMPLE-PE)

The main outcomes of this study have been published in the journal *Children*: **Crotti, M.,** Rudd, J. R., Roberts, S., Boddy, L. M., Fitton Davies, K., O'Callaghan, L., Utesch, T., & Foweather, L. (2021). Effect of Linear and Nonlinear Pedagogy Physical Education Interventions on Children's Physical Activity: A Cluster Randomized Controlled Trial (SAMPLE-PE). *Children*, *8*(1), 49. https://doi.org/10.3390/children8010049

Thesis study map: Chapter 6

Study	**Objectives / Main outcomes**
Study 1: Development of raw acceleration cut-points for wrist and hip accelerometers to assess sedentary behaviour and physical activity in 5-7 year old children	*Main outcomes:* • The raw acceleration cut-points developed for GT9X ActiGraph devices presented acceptable validity and reliability for hip, dominant wrist and nondominant hip placement to assess SB, LPA, MPA and VPA in 5-7 year old children. • Different accelerometer wear position - hip, dominant wrist or nondominant wrist – offer similar accuracy in estimating PA/SB.
Study 2: Validation of modified SOFIT+: relating physical activity promoting practices in physical education to moderate-to-vigorous physical activity in 5–6 year old children.	*Main Outcomes:* • The modified version of the SOFIT+ demonstrated to be a valid and reliable tool to assess teaching practices associated with MVPA in 5-6 years old children in UK. • The new SOFIT+ teaching variables (*Discovery Practice, Instruction Class, Instruction Group, Instruction Single Child and Large sided PA*) demonstrated reliability and were generally associated with children's PA in the expected directions. • The *Activity Management* teaching practices comprising *Signalling*, *Retrieving equipment from one access point*, *Interruption Public*, and *Interruption Private* were generally related with decreased children's MVPA engagement during PE.
Study 3 Teacher Physical Activity Promoting Practices and Children's Physical Activity within Physical Education lessons underpinned by motor learning theories (SAMPLE-PE)	*Main Findings* • PE interventions guided by Linear pedagogy and Nonlinear pedagogy interventions were not associated with different children's MVPA during PE compared to the current practice in PE within the control group and compared to each other. • Linear and Nonlinear pedagogical approaches in PE presented a higher incidence of MVPA promoting teaching (e.g. *Motor content, Skill Practice, Discovery Practice, Individual Activity, PA Engaged*) and lower incidence of MVPA decreasing teaching practices (e.g. *Knowledge, Management, Instructs Class, Off Task*) compared to current practice in PE in the control group.
Study 4: Effect of Linear and Nonlinear pedagogy physical education interventions on children's physical activity: a cluster randomized controlled trial (SAMPLE-PE)	*Objective:* • To evaluate the effect of PE interventions guided by Linear pedagogy and Nonlinear pedagogy on habitual PA over the whole week and different segments of the week compared to the control group (current practice in PE) in 5–6-year-old children.

Thesis context

This study evaluated the effect of the SAMPLE-PE interventions on children's habitual PA (see chapter 1 "*Overview of the SAMPLE-PE project*", page 33). The non-dominant wrist cut-points developed in study 1 (chapter 3) were used in this study to assess children's habitual MVPA during different segments of the week (i.e. whole week, weekend, during school time, after school) and during different time points (i.e. baseline, post-intervention, follow-up).

Introduction

Increased physical activity (PA) in children is associated with positive effects on quality of life (Marker et al., 2018), self-perception (Lubans et al., 2016), cardiovascular fitness (Tarp et al., 2016), metabolic function (Whooten et al., 2019) and cognition (Donnelly et al., 2016). Children who are physically active are also more likely to become healthy and active adults (Telama et al., 2014). Despite these benefits, a large amount of children across the globe do not engage in the recommended guidelines of 60 minutes of moderate-to-vigorous PA (MVPA) per day for healthy growth and development (Janssen and LeBlanc, 2010; Griffiths et al., 2013; Roman-Viñas et al., 2016; Manyanga et al., 2019; Tanaka et al., 2020), with children from areas of deprivation participating in even lower levels of PA (Love et al., 2019a). In view of this, a global call of action was raised to increase PA in children using interventions that could be feasibly implemented at scale (Ding et al., 2020).

School is considered an ideal setting to promote current and future PA on a population level as large numbers of children can be reached (Hills et al., 2015; Chen and Gu, 2018). A recent review by Grao-Cruces et al. (2020) reported that children spend on average between 14 and 61 minutes in MVPA at school, showing that children engage in a considerable amount of PA and can even meet PA guidelines during the school day (Grao-Cruces et al., 2020). Physical education (PE) is a key occasion for children to engage in MVPA during school time with evidence suggesting that children are more physically active during school days including PE than during other school days (Yli-Piipari et al., 2016). PE is not merely an opportunity for children to engage in PA, it is widely recognized as playing a crucial role in the development of knowledge and skills to foster their PA engagement throughout life (Hills et al., 2015; UNESCO, 2015; Hollis et al., 2016; Yli-Piipari et al., 2016). Despite this, there is weak evidence and limited understanding about how learning experiences in PE affect children's PA during school time and outside of school (Tompsett et al., 2017; Errisuriz et al., 2018). Studies reporting a positive effect of PE interventions on children's habitual PA have mostly measured PA using self-report or parent proxy questionnaires (Donnelly et al., 1996; Sallis et al., 1997; Manios et al., 1998; Caballero et al., 2003; Verstraete et al., 2007a; Chatzisarantis and Hagger, 2009; Sacchetti et al., 2013; Telford et al., 2016; Invernizzi et al., 2019; Kokkonen et al., 2019). Self-reported or parent reported PA measurements in children are exposed to risk of bias such as recall and social desirability bias together with the difficulties children have in recognizing different PA levels and constructs (Warren, 2006). Therefore, future studies should assess the effect of PE interventions on PA using device-based measurements, such as accelerometers (Errisuriz et al., 2018).

International and national PE curriculum guidelines state that PE should support young children's development of movement competence (Australian Curriculum Assessment and Reporting Authority, 2013; UK Department of Education, 2013; SHAPE America, 2015; UNESCO, 2015). Movement competence is hereby defined as an individual's degree of proficiently performing a broad range of movement skills, which also affects the underlying mechanisms including quality of movement, motor coordination and motor control (Utesch and Bardid, 2019). Evidence indicates a positive and reciprocal association between movement competence and PA engagement in children, with children possessing high movement competence being more likely to engage in PA during their adolescence and adulthood (Stodden et al., 2008; Loprinzi et al., 2015; Robinson et al., 2015; Lima et al., 2017; Utesch et al., 2018). Thus, learning foundational skills such as catching, bouncing a ball, swimming, leaping, cycling and kicking, could enhance children's actual and perceived capability to engage in PA, sport and recreational opportunities, positively affecting their PA levels (Hulteen et al., 2018). While several studies have examined associations between movement competence and PA, there is limited evidence about how the quality of movement learning experienced through PE influences participation in PA (Robinson et al., 2015; Engel et al., 2018; Errisuriz et al., 2018). PE pedagogical approaches underpinned by motor learning theories from contrasting standpoints such as Linear pedagogy and Nonlinear pedagogy might affect both movement competence development as well as PA engagement (Robinson et al., 2015; Tompsett et al., 2017; Rudd et al., 2020b).

Linear pedagogy is based on the Information Processing Theory (Schmidt, 1975) about learning. Information Processing theory explains how specific inputs (sensory inputs and desired movement outcomes) experienced by learners are elaborated together with previous experiences before commencing the action and during the action based sensory feedback to produce specific movement outcomes leading to learning outcomes (schemas and skill learning) (Fitts and Posner, 1967). From this perspective, providing a set of movement experiences of increasing difficulty should lead to a linear learning progression through cognitive stages (cognitive, associative, autonomous), with improving movement proficiency accompanied by a reduction in cognitive processing while performing (Fitts and Posner, 1967). Linear pedagogy can be characterized by a teacher-centered approach to PE, as a) children should learn the optimal movement patterns for each movement skill and all children should conform to these idealistic movement patterns; b) movement skills should be broken down into basic and simpler movements to facilitate learning; c) movement variability within a task is seen as detrimental for learning and therefore should be reduced; d) teachers in early learning should encourage an internal focus of attention in children who are performing skills to reduce cognitive load, while as children become proficient in the skill teachers would encourage an external attention of focus (Fitts and Posner, 1967; Beilock et al., 2002). While the characteristics of Linear pedagogy are comparable with traditional practices in PE that follow a sport-as-technique approach (Kirk, 2009), Linear pedagogy is based on motor learning theory and should therefore lead to more beneficial outcomes than atheoretical approaches currently employed (Magill, 1990; Metzler, 2017). With teacher-led, Linear approaches, the development of motor proficiency in one optimal technique may result in fast learning, leading to early feelings of success that should increase perceptions of competence, contributing to higher levels of motivation in the lesson, as well as PE and PA more broadly (Susan, 1981; Peers et al., 2020).

Nonlinear pedagogy has been developed and constructed based upon an Ecological Dynamics approach. At the heart of this pedagogical framework is exploratory learning, with an emphasis on encouraging individualized movement solutions (Chow and Atencio, 2014). From this perspective, providing children with the freedom to explore carefully designed learning environment will lead to constraint led synergy formation that will result in the performance of functional movement solutions (Rudd et al., 2020a). Consequently, Nonlinear pedagogy involves a child-centered PE approach where teachers channel children's learning by modifying task constraints to assist synergy formation of skills that will be functional to the task at hand. A key aspect of this is not to over constrain synergy formation as such manipulation of equipment or rules of game would be preferred over providing the child with direct instruction (Chow and Atencio, 2014). For teachers delivering a nonlinear pedagogical approach, movement skills should be practiced in representative environments where perception and action are not broken. This means that learning activities should be situated in performance contexts that capture the dynamics where the skills to be learnt can be performed, developed and acquired. In a Nonlinear pedagogy approach, teachers modify individual, task and environmental constraints to support exploration and with reference to nonlinearity in learning, variability is seen as inherently present in how movement is controlled and produced. Variability in movement control can thus be functional and is to be encouraged. Lastly, in Nonlinear pedagogy, teachers should encourage an external focus of attention to support self-organization. Several authors have proposed that Nonlinear pedagogy could support children's basic psychological needs of autonomy, relatedness and competence from a self-determination theory perspective and therefore could lead to higher levels of motivation towards PA engagement that might positively affect PA levels in children compared to traditional teaching approaches (Moy et al., 2016; Lee et al., 2017; Rudd et al., 2020b).

In summary, primary (elementary) PE is an important setting for PA promotion and child development, especially for children from areas of high deprivation who participate in less PA compared to children from more affluent areas. Movement competence is an important outcome of PE and enhanced learning experiences in PE based on motor learning theory could lead to greater engagement in PA compared to atheoretical approaches used in current practice. To date, no study has examined the effect of Linear and Nonlinear pedagogy PE interventions on children's habitual PA and, more broadly, there is a lack of evidence concerning how interventions aimed at improving movement competence might affect children's PA (Robinson et al., 2015; Engel et al., 2018; Errisuriz et al., 2018). Therefore, the aim of this study was to evaluate the effect of Linear and Nonlinear pedagogy PE interventions on the PA levels of 5-6-year-old children from areas of high deprivation.

Methods

Study design and participants

Ethical approval for the study was granted by the University Research Ethics Committee (Reference 17/SPS/031). This study formed part of the wider SAMPLE-PE project - a registered (ClinicalTrials.gov identifier: NCT03551366) cluster randomized controlled trial evaluating the effect of PE pedagogical approaches guided by motor learning theories on 5-6 years old children's physical literacy (Rudd et al., 2020a). The main trial methods of the study have been described in detail elsewhere (Rudd et al., 2020a). Briefly, primary schools from deprived areas in the North West of England were contacted and invited to take part in the study (Figure 10). The Head-teachers of 12 primary schools provided informed consent to participate in the SAMPLE-PE project.

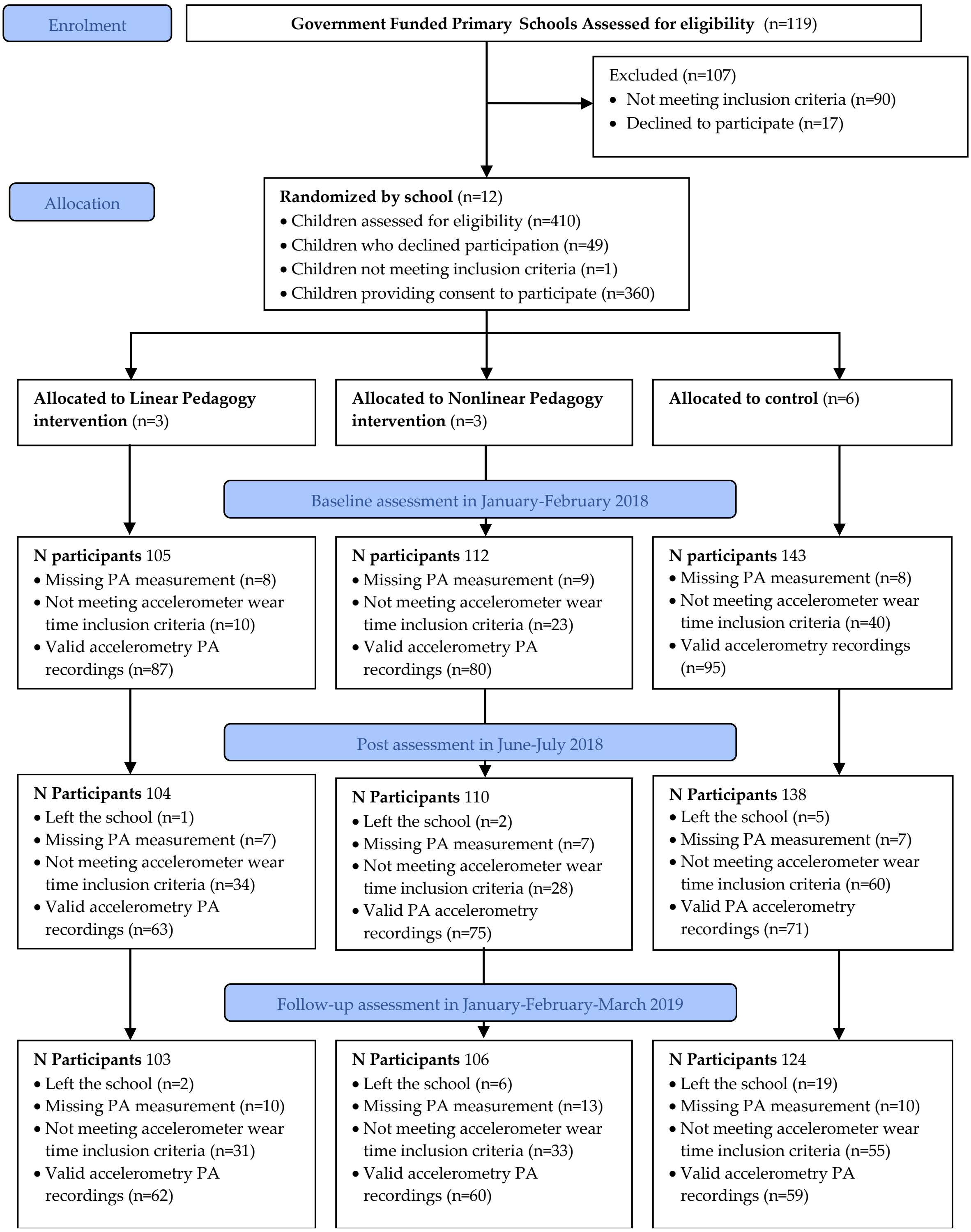

Figure 10. Flow diagram

Subsequently, Year 1 children (5-6-years-old) within the participating schools were invited to take part in the study and parental informed consent together with child assent to participate in the study were collected. The children who did not provide consent to participate in the research study took part in PE lessons both in the intervention and control groups. Children who could not take part in PE because of medical conditions, severe learning disabilities or special educational needs were not eligible to take part in the research.

The 12 schools were randomly allocated to a Nonlinear pedagogy intervention group (3 schools), a Linear pedagogy intervention group (3 schools), or a Control group (6 schools). Baseline data (T0) collection occurred in January-February 2018. The intervention started immediately after baseline assessments and consisted of two PE lessons per week for 15 weeks, delivered by trained coaches. Control group schools were asked to provide their usual PE practice for two lessons per week during the same period. Post-intervention assessments (T1) were completed within 2 weeks after the intervention period between June and July 2018, while follow-up assessments (T2) took place 6 months after post-intervention assessments between January and early March 2019. The design, conduct and reporting of this study was designed in accordance with the Consolidated Standards of Reporting Trials (CONSORT) (Moher et al., 2010).

Intervention deliverers training

This section repeats information reported in Study 3 within the "Deliverer training and intervention delivery" section (page 158).

Given that most of the generalist primary school teachers lack the confidence and competence to effectively teach PE (Morgan and Hansen, 2008), coaches were recruited to deliver the Linear and Nonlinear Pedagogy PE interventions. This in line with current practice in primary PE in England where the majority of primary schools currently employ sports coaches from external providers to deliver PE (Griggs, 2016). Intervention deliverers (coaches) were recruited from a University in-house coaching provider and within the research team. Coaches were required to hold a level 2 UK coaching qualification in any sport. All of the PE coaches recruited in the project were enrolled into a training program to deliver either the Linear or the Nonlinear pedagogy intervention. Before assigning the coaches to one of the training programs, members of the research team observed the coaches while delivering a PE lesson in a primary school not participating in the project. Subsequently, based on the observed lessons, the researchers assigned the coaches to the pedagogical approach training (Linear or Nonlinear) more aligned to their teaching practices. The decision to assign coaches based on their alignment with intervention pedagogies was made to maximize the likelihood of intervention fidelity.

Three coaches were assigned to the Nonlinear pedagogy curriculum training while two coaches received the Linear pedagogy curriculum training. The training consisted of one session a week for 5 weeks delivered by a member of the research team. Each session lasted 3 hours divided evenly into theory and practice. Practical sessions were carried out with Year 2 children (6-7-years-old) from a primary school that was not involved in the randomized controlled trial. At the end of the training, each PE coach received a scheme of work and lesson plans designed by the research team in collaboration with them outlining the content of PE lessons to guarantee consistency in the intervention content delivery. Furthermore, coaches received a pedagogical framework and a resource pack about delivering either a Linear or Nonlinear pedagogical approach. Additionally, the material used during training sessions together with the recording of the sessions were made available for the coaches online. Following the training, coaches were supported by the research team through weekly telephone calls to discuss the design and delivery of lessons and assist in adapting lesson plans (See example of Linear and Nonlinear pedagogy lessons plans in Supplementary Materials 6 and 7) in to their intervention classes.

Interventions

This section repeats information reported in Study 3 within the "Design" (page 156) and "Intervention" (page 157) sections.

The SAMPLE-PE interventions are described in detail within the study protocol (Rudd et al., 2020a). Briefly, the main aim of the wider SAMPLE-PE project was to assess the effect of Linear and Nonlinear pedagogies in fostering physical literacy among 5-6-year-old children from deprived areas of North-West England. Given that Linear and Nonlinear pedagogies are based on motor learning theories, the primary outcome in the SAMPLE-PE project was movement competence. Both Linear and Nonlinear pedagogy interventions lasted 15 weeks and comprised thirty PE lessons, which were divided into three content blocks of five weeks corresponding to 10 lessons each focusing on "Dance", "Gymnastic" and "Object control skills" as overarching themes. The overarching themes of each PE lesson specified in the intervention deliverers' scheme of work (e.g. "Fast and slow movements" in a Dance lesson, "Rolling" in a Gymnastic lesson, "Underarm throw" in an Object control lesson) were the same for both Linear and Nonlinear pedagogy interventions to minimize content differences between Linear and Nonlinear curricula. Intervention duration was chosen based on previous literature showing that interventions lasting between 6 and 15 weeks are effective in increasing children movement competence (Logan et al., 2012; Foweather and Rudd, 2020).

Linear pedagogy intervention

This section repeats information reported in Study 3 within the "Linear Pedagogy Intervention delivery" section (page 159).

The well-established principles and theories of direct instruction were used by the research team and trained PE coaches to guide the design of the Linear intervention (Metzler, 2017). Consequently, Linear pedagogy PE lessons generally followed a traditional structure involving:

1) a warm-up activity, 2) practicing passive movement skills within drills, 3) a performance or game activity to apply the movement skills learnt during the lesson and 4) a cool down (Supplementary material 6). Coaches were asked to provide clear instructions and demonstrations to the children before each task, and to provide augmented corrective feedback during each activity. Emphasis was given to executing and reiterating passive movement skills in a desired performance or outcome as previously demonstrated by the coach. Coaches used the principles from Gentile's taxonomy and challenge point framework (Adams, 1999; Guadagnoll and Lee, 2004) to create progressions of tasks of increasing difficulty from simple and controlled movements to complex and dynamic actions. Coaches were trained to evaluate children's progression in movement skills proficiency using Fitts and Poster's cognitive stages (cognitive, associative, autonomous) (Fitts and Posner, 1967) and to adapt the difficulty of the tasks based on children's skill level.

Nonlinear pedagogy intervention

This section repeats information reported in Study 3 within the "Nonlinear Pedagogy Intervention delivery" section (page 159).

Nonlinear pedagogy theories and principles were used by the research team and trained PE coaches to guide the design of the Nonlinear intervention (Moher et al., 2010). Specifically, the research team together with the coaches delivering the intervention identified relevant constraints to design PE lessons including environmental (e.g. space boundaries, equipment type, equipment number, spatial organization of objects), task (e.g. activity type, rules within a task, duration of the task, number of participants) and individual constraints (e.g. age, sex, socioeconomic demographic). At the beginning of each lesson, coaches invited children to explore the PE hall and the different objects within the environment (e.g. benches, mats, hoops, cones). The lesson continued with activities representative of game, sport or performance situations where coaches introduced variability by changing constraints (Supplementary material 7). Coaches used the Space Task Equipment People (STEP) framework to identify and manage constraints within the lessons (STEP Academy Trust, 2015). Furthermore, coaches were trained to monitor children's progress in movement learning using Newell's stages of motor learning (coordination, control and skill) and to modify and individualize constraints based on children's motor learning stage (STEP Academy Trust, 2015). Coaches did not provide demonstrations or feedback during activities. Alternatively, they invited children to reflect using questioning strategies or to observe their peers. Coaches also used questioning to foster an external focus of attention in the child to infuse variability in the task and channel children learning (e.g. how could we make this task more difficult? How can your teammates help you in this task? How many ways to move on the floor can you think about?).

Outcomes and data collection timeline

Demographic outcomes were collected during baseline data collection (January-February 2018) while anthropometric and PA outcomes were collected during each data collection point comprising baseline, post-intervention (June-July 2018) and follow-up (January-early March 2019) (Figure 10).

Demographics

Information about children's demographics (i.e. date of birth, gender, ethnicity, home postcode and special educational needs) were provided by parents or guardians within a questionnaire that was returned with the consent form. Household postcode was used to classify children into deciles of deprivation level using the English indices of deprivation (UK Government Ministry of Housing Communities & Local, 2018).

Anthropometrics

Children's anthropometric measurements took place within the schools. Stature (The Leicester Height Measure, Child Growth Foundation, Leicester, United Kingdom), to the nearest 0.1 cm, and mass (model 760, Seca, Hamburg, Germany), to the nearest 0.1 kg, were measured using standard procedures (Dettwyler, 1993). All measurements were taken twice while a third measurement was taken if the first two differed by more than 1%. Body Mass Index was calculated and converted to standardized BMI z-scores using the International Obesity Task Force (IOTF) classification (Hinckson and Curtis, 2013).

Physical activity

PA was assessed using ActiGraph GT9X accelerometers (ActiGraph, Pensacola, FL, USA) set to record accelerations at 30Hz over 1 second epochs within a range of ±8 g on x, y and z axes. Children were asked to wear a GT9X accelerometer on their nondominant wrist for an entire week and to only remove the device when having a bath, swimming, or for safety reasons. Furthermore, children were encouraged to wear the monitor all day including sleeping hours, and to bring the device back to school on a specific date (i.e. 7 days after receiving it). Each participant received an accelerometer directly from a trained researcher within their school together with an information pack for the parents or guardians including a wear time diary and information about when to return the device to the school. Parents or guardians were asked to fill in the diary and record times when their child took off the device as well as the time when the child went to sleep and woke-up. Where children did not wear the device for at least 3 weekdays and one weekend day for 10 valid hours, they were invited to wear the device again for an entire week. Teachers were asked to report to the research team whether the school had organized any special sport or activity events during school time during each measurement period that were not part of the normal school week and could disrupt children's regular PA engagement patterns.

Following previous studies (Van Kann et al., 2016; Strutz et al., 2018), children's awake time was established as a standard period between 06:00 a.m. 23:00 p.m. as the majority of the children did not wear the monitor during night time. Consequently, sleep time was established as a standard period between 23:00 and 06:00 and all PA analysis included awake time only. Classification of valid wear time was done following GGIR package default option over blocks of 15 minutes where each block was classified as non-wear time when the standard deviation of the 60 minutes interval around the block was less than 13 mg in at least 2 of the three axes or if the value range for at least 2 of the three axes was less than 50 mg (Van Hees, 2020). A day of measurement was considered valid only when the participant had at least 10 hours of valid wear time during waking hours while a measured week was considered valid when the participant was assessed over at least 3 valid week days and 1 valid weekend day (Montoye et al., 2018). Children's PA levels during non-wear time were imputed based on recordings from other days as default in GGIR package (Van Hees, 2020). In cases where children were re-monitored, the valid days from the first monitoring session and the re-monitoring session within the same assessment point (e.g. baseline) were pooled together. Only PA data from valid days within valid weeks were included in the final analysis. Furthermore, mean rainfall, mean temperature and daylength specific to the valid PA data was obtained from "Metoffice" website (Met Office Hadley Centre, 2018) and "Timeanddate" website (timeanddate.com, 2018) to account for seasonal variation in PA outcomes across each time point.

Raw acceleration data were downloaded from accelerometers in 1 s epochs and exported as .csv files using ActiLife software version 6.11.9 (ActiGraph, Pensacola, FL, USA). Raw data were then transformed into Euclidean Norm Minus One (ENMO) acceleration data using GGIR package (Van Hees, 2020) from R software Version 4.0.2 (www.r-project.org). Subsequently, GGIR package was used to compute Mean ENMO acceleration, the minimum acceleration within the most active hour of the day (M60), the minimum acceleration within the most active half an hour of the day (M30) (Rowlands et al., 2019; Fairclough et al., 2020) together with time spent in MVPA based on age appropriate cut-points (Crotti et al., 2020). Mean ENMO, M60 and M30 were included as PA metrics in view of recent calls to use cut-point free metrics to facilitate the comparison of PA outputs from different brands of accelerometers and also to get a deeper insight on children's PA engagement beyond MVPA (Fairclough et al., 2020). Mean ENMO acceleration differs from MVPA as it represents the magnitude of total PA accumulated during the recording time and was found to be positively associated with health related outcomes in children (Fairclough et al., 2019). M60 was chosen as a PA metric for whole week and weekend as children are meant to engage in at least 60 min of MVPA per day and M60 provides a valuable information about how active children were in their most active 60 minutes in a day. Following a similar rationale, M30 was included to assess PA within school time and outside of school in accordance with UK targets for primary school children to engage in 30 min of MVPA in school and 30 min of MVPA outside of school to achieve the recommended daily 60 minutes of MVPA (UK Government, 2017; Sport England, 2019). Furthermore, M30 was found to be associated with health related outcomes comprising BMI, waist-to-height ratio and cardiorespiratory fitness in children (Fairclough et al., 2020).

Intervention fidelity

This section repeats information reported in Study 3 within the "Fidelity" section (page 163).

The research team developed a checklist to assess fidelity of the intervention through the video analysis of recorded PE lessons (Supplementary Material 8). The checklist included 9 items comprising 7 motor learning related items and 2 global items. Each item was scored on a 1 to 5 Likert sale, where a score of 1 corresponded to the observation being in line with Linear pedagogy while a score of 5 corresponded to the observation being in accordance with Nonlinear pedagogy. Each Motor learning related item was assessed 4 times within each lesson (once for each quartile of the PE lessons) while global items were assessed only once per lesson observed. Two independent researchers that were blinded to the group allocations were trained to code the lessons. The training consisted of: 1) reading specific literature concerning Linear and Nonlinear pedagogy, 2) reading the fidelity checklist, 3) consulting the research team about doubts concerning the checklist, 4) independently coding 2 PE lessons, 5) consulting a pedagogy expert to check the coded lessons and clarify any doubts, 6) collaborating to assess 6 PE lessons, 7) independently assessing 6 lessons and then compare the results. The coders then assessed fidelity using the Fidelity Checklist within a total of 13 randomly selected PE lessons from Linear pedagogy, Nonlinear pedagogy and Control group. Raters demonstrated high inter-rater reliability with ICC equal to or higher than 0.97.

Randomization and power

The participating schools were matched by number of students enrolled and then they were randomly allocated to either intervention or control group using a computer-based algorithm. As a result, more schools were allocated to the control group to account for the higher risk of drop out as a consequence of not receiving the intervention. The study was powered as reported in the SAMPLE-PE project protocol paper (Rudd et al., 2020a) to assess movement competence change in 3 groups over 3 time points with a 90% power at a level of $p < 0.05$ adjusting for clustering at class level and allowing a dropout at each time point equal to 20%. As a result, the initial sample calculation aimed to recruit at least 314 participants. It was not possible to perform a sample size and power calculations based on PA outcomes as no meta-analysis reported effect-sizes concerning changes in habitual PA due to PE interventions. Additionally, no pilot study assessed the effect of Linear pedagogy and Nonlinear pedagogy PE interventions on habitual PA in children. However, different studies involving PE interventions aiming to increase habitual PA in children presented a number of participants that was similar or lower than 314 children (i.e. between 82 and 338) (Donnelly et al., 1996; Bryant et al., 2016; Invernizzi et al., 2019; Kokkonen et al., 2019). Furthermore, samples ranging in size from 10 to 40 per group are considered adequate for Pilot studies (Hertzog, 2008). Therefore, a sample of 314 children with more than 100 children per intervention group could be considered an adequate sample size for a randomized controlled trial evaluating the effect of PE interventions on habitual PA in children.

Data analysis

All data analysis was carried out using R Software (Version 4.0.2, www.r-project.org) and RStudio Software (Version 1.3.1056, www.rstudio.com). The main effect of time (the change from one timepoint to the next, averaged across groups), group (i.e. the difference between groups averaged across timepoints) and group by time interaction effects (the extent to which the difference between intervention and control groups is different at different timepoints) in children's PA variables comprising MVPA, Mean ENMO, M60 and M30 were assessed using multilevel linear regression models. Separate multilevel models were conducted to examine PA variables during whole week (habitual PA), weekend, school time (9am to 3pm) and outside school (3pm to 11pm) during weekdays. Models considering the nested data structure were selected to maximize model fit assessed using Chi-squared test while minimizing the complexity of the final model. Overall, observations (level 1) were nested within children (level 2) in multilevel models concerning whole week, weekend and week time outside school PA variables as nesting by class (level 3) or school (level 4) was not increasing model fit or led to overfitting. Conversely, observations were nested within children and class in all multilevel models concerning school time PA variables as nesting by children and by class was leading to the best model fit. Based on previous studies identifying PA correlates all models were adjusted for decimal age (Cooper et al., 2015), sex (Deng and Fredriksen, 2018; McLellan et al., 2020), International Obesity Task Force (IOTF) BMI z-score (Owen et al., 2010), special educational needs (Hinckson and Curtis, 2013), ethnicity (Love et al., 2019a), school sport events (Ridgers et al., 2005) and household neighborhood deprivation decile (UK Government Ministry of Housing Communities & Local, 2018). Furthermore, models were adjusted for accelerometer valid wear time (Herrmann et al., 2014), mean rainfall, mean temperature and daylength (Goodman et al., 2012; Harrison et al., 2017) specific to the time of the week considered in the model. Different variables presented missing data including PA variables, decimal age, BMI z-score, special educational needs, ethnicity and household neighborhood deprivation, valid wear time, mean rainfall, mean temperature and daylength. Ignoring missing data and running a complete cases analysis was not an appropriate strategy to analyse data and could lead to biased results as more than 5% of PA data were missing and it could not be established whether data were missing completely at random (Groenwold et al., 2014; Jakobsen et al., 2017). Based on published guidelines about dealing with missing data in randomized trials, Multiple Imputation methods were used to impute missing data (Thabane et al., 2013; Groenwold et al., 2014; Jakobsen et al., 2017). Then an intention to treat analysis on imputed data was performed as a main analysis and a complete cases analysis was employed as sensitivity analysis (Thabane et al., 2013; Jakobsen et al., 2017). More specifically, complete cases analysis was conducted in order to examine whether between group effects differed from the intention to treat data analysis. Missing data (see supplementary material 9 for details) were imputed applying "Multivariate Imputation by Chained Equations" Multiple Imputation method using "mice" Package employing "Jomoimpute" function (van Buuren et al., 2020) within R software. A specific imputation was performed for each multilevel model comprising all the variables to be included in the model, accounting for multilevel nesting together with time by group interaction and creating 10 datasets of imputed data (Van Buuren Stef, 2018). Separate multilevel models were run using each of the imputed datasets and then the estimates from the models were pooled

(Rubin, 2004; Van Buuren Stef, 2018). The same multilevel linear regression model methods were also used to analyze the dataset without imputation.

Results

Figure 10 shows the flow of schools and participants through the trial. In total, 12 schools participated in the study (10 % response rate). Schools that declined to participate provided diverse reasons for not taking part (e.g. too busy, already in receipt of external projects). Of the 410 potentially eligible children at T0 (baseline), 360 children were enrolled into the study (88% response rate) and 307 children (85% of participants) had valid PA data at either baseline, post-intervention and/or follow-up. Reasons for missing data included children being absent on data collection days, leaving school, declining to undertake measurement procedures, losing accelerometers, or not meeting the PA inclusion criteria (see Supplementary Material 9). Participant retention in the study from baseline to follow-up was 98%, 95% and 87% for the Linear pedagogy, Nonlinear pedagogy and Control group, respectively, with a larger proportion of control group children leaving school within the study period.

Baseline characteristics

Table 20 shows the demographic and baseline characteristics of the study sample by group. The pooled sample comprised 360 children (55% girls) with a mean age of 5.9 (Standard Deviation [SD] = 0.3) years; 56% of the children were white British while 44% were from other ethnicities; 12% reported special educational needs of mild and moderate severity and the vast majority lived in highly deprived areas with 85% of the children living in areas amongst the 30 per cent most deprived in England. Based on the International Obesity Task Force (IOTF) classifications, 17% of children were overweight and 6% were obese, while BMI was not assessed in 12% of children due school absences. Of the 262 children with valid baseline PA data, 65%, 71% and 51% engaged in an average of 60 or more minutes of MVPA during the whole week, weekdays and weekend respectively. Descriptive statistics concerning child characteristics in all outcome measures by group at baseline, post-intervention and follow-up assessments can be found in supplementary material 10.

Table 20 Baseline characteristics of children by group

	Linear Pedagogy (n=105)		**Nonlinear Pedagogy (n=112)**		**Control (n=143)**	
Baseline Characteristic	**Mean (SD) or %.**	**Missing data**	**Mean (SD) or %**	**Missing data**	**Mean (SD) or %**	**Missing data**
Decimal Age (years)	6.0 (0.3)	5	5.9 (0.3)	1	5.9 (0.3)	2
Girls	53%	0	52%	0	58%	0
White British	68%	8	52%	9	50%	5
SEN	8%	1	15%	1	12%	0
Living within the 30% most deprived areas (IMD)	96%	4	77%	1	89%	3
IOTF SDS BMI	0.4 (1.3)	9	0.5 (1.1)	8	0.3 (1.1)	27
Thinness grade 3	1%		0%		1%	
Thinness grade 2	2%		1%		0%	
Thinness grade 1	6%		4%		6%	
Healthy weight	61%		72%		67%	
Overweight	21%		14%		22%	
Obese	8%		9%		4%	
Meeting PA guidelines						
Whole week	68%	18	64%	32	62.1%	48
Weekdays	70%	18	71%	32	71.6%	48
Weekend	53%	18	48%	32	53%	48

SD: Standard deviation; **NA:** missing data; **SEN:** Special educational needs; **IMD:** Index of multiple deprivation; **PA:** physical activity.

Fidelity assessment

This Paragraph repeats information reported in Study 3 within the "Pedagogic Fidelity" section (page 166).

Table 21 reports means and standard deviations of the pedagogy fidelity assessment. Nonlinear pedagogy intervention fidelity scores were all higher than 4 apart from category 4 that presented a score equal to 3.95. Linear pedagogy intervention fidelity scores were all lower than 1.77, while control group scores ranged from 1.44 and 2.50. Given that scores of 1 and 2 on the Likert scale correspond to the observation being more in line with Linear pedagogy and scores of 4 and 5 correspond to the observation being in line with Nonlinear pedagogy, the fidelity check observation data indicated that Linear and Nonlinear interventions were delivered in line with their respective pedagogical principles. The control group presented characteristics that indicated closer alignment towards Linear pedagogy principles.

Table 21. Pedagogical fidelity checklist results

This Table is the same as Table 14 reported in Study 3 within the "Results" section (page 167).

	Category							**Global**	
	Category Mean (SD)							**Global Mean (SD)**	
	1	**2**	**3**	**4**	**5**	**6**	**7**	**1**	**2**
Nonlinear	5.00 (0.00)	5.00 (0.00)	4.90 (0.28)	3.95 (0.78)	4.05 (0.77)	4.73 (0.41)	4.58 (0.43)	5.00 (0.00)	5.00 (0.00)
Linear	1.40 (0.64)	1.48 (0.85)	1.20 (0.41)	1.77 (0.94)	1.20 (0.41)	1.63 (0.88)	1.63 (0.75)	1.40 (0.74)	1.33 (0.82)
Control	2.10 (0.83)	2.15 (1.04)	2.19 (0.88)	1.44 (0.97)	2.33 (0.87)	2.21 (0.75)	2.50 (0.54)	2.00 (1.08)	1.92 (1.11)

Intervention effect on physical activity outcomes

The full outputs from the 24 multilevel models, including covariates, can be found in supplementary material 11 (intention to treat analysis) and supplementary material 12 (complete case analysis). Tables 22 and 23 present model summaries in relation to intervention effects. The intention to treat analysis involved imputed data from all 360 children with a total of 1080 complete observations in each variable. There were no significant group by time interaction effects in all the PA outcomes, inclusive of MVPA, Mean ENMO, M60 and M30 for both whole week and weekend periods (see Table 22). As shown in Table 23, no significant group by time effects were observed for PA outcomes during school time (09:00 to 15:00) and outside of school (15:00 to 23:00) during weekdays. No group effects (i.e. the difference between groups using data averaged across T0, T1 and T2) were observed, apart from Linear pedagogy group presenting lower M30 (β = -45.45 mg, SE = 14.54 mg, p = .045) compared to the control group within school time. For time effects (i.e. the change from one timepoint to the next, averaged across groups), it was observed that MVPA and mean ENMO decreased at follow-up during weekend only.

The multilevel models complete case analysis involved data from 274 children with a total of 575 observations in each variable (53.2% of observations: see supplementary material 9 for missing data information). Group by time interaction effects from the complete case analysis were largely consistent with the intention to treat analysis, with some exceptions (see Table 22 and Table 23). Specifically, at post-intervention (T1), a significant group by time interaction effect was found for the Linear pedagogy interventions on MVPA and mean ENMO out of school weekday PA metrics, with negative intervention effects observed relative to the control group (MVPA: β = -7.74 min, SE = 3.71 min, p = .037; Mean ENMO: β = -12.24 mg, SE = 5.89 mg, p = .038). No significant group by time interaction effects were found for out of school weekday PA metrics at follow-up. At follow-up (T2), a significant group by time interaction effect was found for Nonlinear pedagogy for MVPA in school, indicating a positive intervention effect compared to the control group (β = 5.18 min, SE = 2.11 min, p= .014). No group effects were observed, apart from the Linear pedagogy intervention group presenting on average higher MVPA (β = 4.85 min, SE = 2.26 min, p = .032), Mean ENMO (β = 8.45 mg, SE = 3.59 mg, p = .019) and M30 (β = 30.66 mg, SE = 14.90 mg, p = .040) for out of school PA compared to the control group. In relation to time effects, M60 during the weekend decreased from baseline to post-intervention. Furthermore, at least one or more PA metrics were found to be lower at follow up compared to baseline for whole week, weekend and school time segmented periods.

Table 22. Intervention effects on whole week and weekend physical activity

	MVPA			**Mean ENMO**			**M60**		
Predictors	**β**	**SE**	***p***	**β**	**SE**	***p***	**β**	**SE**	***p***
WHOLE WEEK PA									
Intention to treat analysis									
Group [NLP] * Time [T1]	−2.62	3.17	0.414	−1.881	2.652	0.483	−1.805	10.466	0.864
Group [NLP] * Time [T2]	1.57	3.75	0.680	0.402	2.448	0.870	3.156	11.981	0.794
Group [LP] * Time [T1]	−0.64	4.04	0.876	−0.936	2.85	0.743	−0.071	14.383	0.996
Group [LP] * Time [T2]	−2.07	3.33	0.538	−2.204	2.539	0.390	−1.692	11.085	0.879
Complete case analysis									
Group [NLP] * Time [T1]	−2.02	3.71	0.587	−0.32	2.90	0.913	0.28	14.03	0.984
Group [NLP] * Time [T2]	5.73	4.35	0.188	4.52	3.40	0.183	3.12	16.44	0.849
Group [LP] * Time [T1]	−1.63	4.94	0.742	−1.65	3.86	0.668	−6.98	18.67	0.708
Group [LP] * Time [T2]	−1.22	4.04	0.762	−0.80	3.16	0.799	−10.63	15.28	0.487
WEEKEND PA									
Intention to treat analysis									
Group [NLP] * Time [T1]	−2.50	4.68	0.595	−0.75	4.26	0.861	7.55	14.69	0.608
Group [NLP] * Time [T2]	1.67	5.39	0.758	2.74	4.16	0.515	7.61	14.86	0.610
Group [LP] * Time [T1]	0.64	4.88	0.897	−0.81	4.02	0.841	4.76	18.96	0.803
Group [LP] * Time [T2]	−3.91	4.87	0.426	−1.74	4.18	0.680	−13.69	14.70	0.355
Complete case analysis									
Group [NLP] * Time [T1]	−1.18	5.86	0.841	1.97	4.44	0.656	19.29	23.17	0.405
Group [NLP] * Time [T2]	9.41	6.57	0.152	8.71	4.97	0.080	33.42	25.96	0.198
Group [LP] * Time [T1]	0.88	7.40	0.905	−0.28	5.60	0.959	12.70	29.26	0.664
Group [LP] * Time [T2]	−0.88	5.87	0.881	−0.91	4.44	0.838	−2.41	23.19	0.917

Control group is the reference category**; MVPA:** Moderate to vigorous physical activity; **ENMO**: Euclidean norm minus one; **M60:** minimum acceleration in the most active hour; **β:** estimate; **SE:** standard error; **p:** p-value; ***:** Interaction; **T0:** Baseline; **T1:** Post Intervention **T2:** Follow-up; **NLP:** Nonlinear Pedagogy group; **LP:** Linear Pedagogy group; **CG:** Control group; Multilevel models were adjusted for decimal age, sex, International Obesity IOTF BMI z-score, special educational needs, ethnicity, school sport events, IMD household neighbourhood deprivation decile, valid wear time, mean rainfall, mean temperature and daylength; PA data were nested within child.

Table 23. Intervention effects on physical activity in school and out of school on weekdays

	MVPA			Mean ENMO			M30		
Predictors	**β**	**SE**	***p***	**β**	**SE**	***p***	**β**	**SE**	***p***
IN SCHOOL WEEKDAY PA									
Intention to treat analysis									
Group [NLP] * Time [T1]	−1.56	1.55	0.318	−3.29	3.57	0.358	−14.94	13.151	0.257
Group [NLP] * Time [T2]	2.23	1.57	0.162	1.45	5.19	0.783	−3.185	15.374	0.837
Group [LP] * Time [T1]	0.81	2.27	0.724	0.71	5.02	0.887	−5.437	18.36	0.768
Group [LP] * Time [T2]	0.39	1.48	0.792	2.62	3.72	0.482	2.341	14.128	0.869
Complete case analysis									
Group [NLP] * Time [T1]	0.16	1.78	0.930	−0.86	4.61	0.852	−14.68	20.57	0.475
Group [NLP] * Time [T2]	**5.18**	**2.11**	**0.014**	7.42	5.46	0.174	−25.53	24.34	0.294
Group [LP] * Time [T1]	1.98	2.56	0.439	1.33	6.64	0.841	−4.73	29.59	0.873
Group [LP] * Time [T2]	2.34	2.01	0.244	5.08	5.20	0.329	−6.74	23.19	0.771
OUTSIDE SCHOOL WEEKDAY PA									
Intention to treat analysis									
Group [NLP] * Time [T1]	−2.09	2.11	0.326	−1.58	3.20	0.623	3.24	13.46	0.811
Group [NLP] * Time [T2]	−0.28	2.27	0.902	0.49	3.83	0.899	10.71	13.04	0.413
Group [LP] * Time [T1]	−4.17	2.69	0.126	−5.84	4.78	0.228	−15.90	16.16	0.327
Group [LP] * Time [T2]	−3.89	2.19	0.079	−4.30	3.73	0.253	0.11	12.67	0.993
Complete case analysis									
Group [NLP] * Time [T1]	−2.61	2.64	0.323	−3.37	4.19	0.421	−4.48	17.59	0.799
Group [NLP] * Time [T2]	0.61	3.07	0.844	0.52	4.87	0.916	6.64	20.43	0.745
Group [LP] * Time [T1]	**−7.74**	**3.71**	**0.037**	**−12.24**	**5.89**	**0.038**	−48.03	24.70	0.052
Group [LP] * Time [T2]	−4.41	2.94	0.134	−7.44	4.66	0.111	−23.25	19.58	0.235

Control group is the reference category; **MVPA:** Moderate to vigorous physical activity; **ENMO**: Euclidean norm minus one; **M30:** minimum acceleration in the most active half hour; **β:** estimate; **SE:** standard error; **p:** p-value; *** :** Interaction; **Vs:** versus; **T0:** Baseline; **T1:** Post Intervention **T2:** Follow-up; **NLP:** Nonlinear Pedagogy group; **LP:** Linear Pedagogy group; **CG:** Control group; Multilevel models were adjusted for decimal age, sex, International Obesity IOTF BMI z-score, special educational needs, ethnicity, school sport events, IMD household neighbourhood deprivation decile, valid wear time, mean rainfall, mean temperature and daylength; Data were nested within child for out of school PA and nested within child and class for within school PA.

Effects of covariates on physical activity outcomes

The intention to treat multilevel analysis results including full models with covariates can be found in supplementary material 11. Neighborhood deprivation decile index was not associated with PA in any of the segments of the week or during the whole week. Sex (boys higher) was significantly associated with MVPA, Mean ENMO, M60 and M30. Decimal age was significantly and positively associated with increased Mean ENMO during the whole week and MVPA during the weekend. Presenting special educational needs was significantly associated with decreased mean ENMO and M30 outside school. IOTF SDS BMI was significantly and negatively associated with M60 during whole week only. Significant associations were found between Ethnicity and MVPA, Mean ENMO, M60 and M30 respectively. Specifically, White British children presented higher levels of mean MVPA, mean ENMO and M60 during weekend, higher mean ENMO and M60 during the whole week and lastly higher mean ENMO and M30 out of school. The participation in a sport event within school (e.g. school sports week) was positively associated with MVPA, mean ENMO and M30 only during school time. For environmental variables, rainfall was significantly and negatively associated with engagement in both MVPA during the whole week, within school time and outside school, it was negatively associated with mean ENMO during whole week, weekend and outside school, while it was negatively associated with M60 during the whole week and weekend. Furthermore, percentage of daylight over a day was significantly associated with increased MVPA within all the week segments and mean ENMO within all the week segments apart from school time while it was positively associated with M60 during the weekend and M30 out of school. Mean daily temperature was positively associated with mean ENMO and M30 during school time only. Accelerometer valid wear time was significantly associated with increased MVPA and mean ENMO within all the week segments apart from school time while wear time was positively associated with M30 out of school.

Discussion

This study aimed to evaluate the effect of Linear and Nonlinear pedagogy PE interventions on the PA levels of 5-6-year-old children from areas of high deprivation. The findings of this study suggest that participation in the Linear and Nonlinear pedagogy PE interventions did not lead to increased PA compared to participation in the control group. This lack of intervention effect was generally consistent across intention to treat and complete case analysis and across all PA metrics and whole week (habitual), weekend, weekday in school and weekday outside of school segmented periods for PA. These findings suggest that enhanced PE would need to be extended and supplemented by whole school approaches to PA promotion and multi-component interventions targeting home and community settings to increase PA among this population.

Results presented from the intention to treat analysis using imputed data and the complete cases analysis concerning the examination of group effects and group by time interaction effects for PA outcomes were generally similar, with some exceptions. Specifically, the complete case analysis found a significant group by time interaction effect for MVPA within school at follow-up (T2) in favour of the Nonlinear pedagogy intervention, compared to control group. Significant group by time interaction effects were also observed in outside of school PA metrics at post-intervention (T1), with participation in the Linear pedagogy intervention associated with lower PA metrics, relative to control group participants. Nevertheless, the positive intervention effect found in the Nonlinear pedagogy group for MVPA in school during weekdays at follow-up was not confirmed by any other result. Furthermore, the negative intervention effect found in the Linear pedagogy group for out of school PA during weekdays at post-intervention assessments might be due to the Linear pedagogy group presenting significantly higher levels of PA compared to control group within the complete case analysis, and therefore potential regression to the mean in this sample (Bland and Altman, 1994). The differences between the intention to treat analysis and complete case analysis might also be attributed to a lack of statistical power within the complete cases analysis and the exclusion of 73 valid PA observations because of missing covariates (i.e. listwise deletion), which might have affected the results (Grund et al., 2018). Overall, the complete cases analysis did not provide strong evidence for an intervention effect on children's PA and therefore the results from the intention to treat analysis were accepted as an accurate portrayal of between-group differences.

The lack of Linear and Nonlinear pedagogy intervention group improvements in PA outcomes is consistent with previous research that has examined the effectiveness of PE interventions on children's habitual PA using device-based methods (Sallis et al., 1997; Caballero et al., 2003; Verstraete et al., 2007a; Telford et al., 2016). These findings are in contrast to studies employing self-report or parent proxy measures, which have generally found that PE interventions have increased habitual PA levels (Donnelly et al., 1996; Sallis et al., 1997; Manios et al., 1998; Caballero et al., 2003; Verstraete et al., 2007a; Chatzisarantis and Hagger, 2009; Sacchetti et al., 2013; Telford et al., 2016; Invernizzi et al., 2019; Kokkonen et al., 2019). Nevertheless, results from self- or parent-proxy reported PA measurement should be interpreted cautiously due to factors such as recall bias, social desirability bias and the difficulty for children in classifying PA intensities and domains (Warren et al., 2010). In comparison to the present study, the interventions examining the effect of PE on PA using device-based methods lasted for a longer duration (i.e. between 2 and 4 years) and involved older children (i.e. children aged between 8 and 11 years) (Sallis et al., 1997; Caballero et al., 2003; Verstraete et al., 2007a; Telford et al., 2016). Furthermore, the majority of these interventions included additional intervention components outside of PE (e.g. classroom sessions), but still found no effect on PA (Sallis et al., 1997; Caballero et al., 2003; Verstraete et al., 2007a; Telford et al., 2016). Based on a thorough search of the literature, only Manios et al. (1998) has conducted a PE intervention and examined PA amongst a similar age group (6-7 years old). Their study reported that participation in a three-year PE intervention significantly increased children's self-reported PA. Aside from the limitations attached to using a self-report measure, the positive effects in this study may be because the intervention focused on fitness rather than movement competence and incorporated classroom-based health and nutrition sessions. It is possible that the lack of an intervention effects in the current study could be due to the length of the PE intervention not being sufficient to impact on PA outcomes (2 lessons per week for 15 weeks). Only two studies (Chatzisarantis and Hagger, 2009; Invernizzi et al., 2019) have reported PE interventions with a similar duration compared to the current study (i.e. 5 to 12 weeks). These interventions targeted teaching practices and teaching styles to improve children's motivation towards PA engagement and foster physical literacy, respectively. Both reported significant increases in self-reported PA in children but did not involve device-based PA measurements (Chatzisarantis and Hagger, 2009; Invernizzi et al., 2019). Recently, Lahti et al. (2018) showed that children participating in daily PE during each school day maintained increased levels of habitual PA over the years compared with children who participated in only 60 minutes of PE per week. This suggests that a stronger dose of the SAMPLE-PE interventions may be needed to obtain positive intervention effects on children's habitual PA levels.

This study showed that PE interventions based on different pedagogical approaches did not lead to increased PA in children compared to PE delivery that followed usual practice. Nonetheless, different variables were consistently related with increased PA such as participation in school sport week events (Ridgers et al., 2005) or increased daylight (Goodman et al., 2012; Harrison et al., 2017). The positive associations between PA and both participation in sport events during school and daylight percentage indicates that children were more active when they had more opportunities to be active. This suggests that providing children with high quality movement experiences in PE might not be sufficient to increase children's PA if children are not provided with more and better occasions to be active - both at school and outside school - alongside the necessary equipment (Beets et al., 2016). For children this age, daily activities are generally dictated by adults (e.g. teachers or parents) and children have low autonomy over their activity choices. This is consistent with research showing that supporting parents in setting PA goals and planning time for their children to be physically active were generally effective in increasing children's PA (Brown et al., 2016). Furthermore, children from deprived areas are provided with less opportunities to be active and the neighborhood is generally not seen as a safe place for children to play without supervision (Noonan et al., 2016). Thus, it might be difficult for children to apply what is experienced in PE within different settings and contexts outside of school (Huberty et al., 2012; Xu et al., 2015). Despite the lack of intervention effects, the focus of the Linear and Nonlinear PE interventions on movement competence may lead to higher levels of PA and sport participation in later childhood and adolescence, as the association between actual and perceived competence and PA strengthens over time (Stodden et al., 2008; Loprinzi et al., 2015; Robinson et al., 2015; Lima et al., 2017; Utesch et al., 2018). More specifically, children who developed a better repertoire of movement skills in early childhood would have an increased actual and perceived capability to engage in wide variety of PAs compared to their peers presenting poorly developed movement skills and therefore they would be more likely to engage in PAs, sports and recreational opportunities later on in their life (Robinson et al., 2015; Barnett et al., 2016; Hulteen et al., 2018).

When considering PA measurement at baseline, more than half of children met the PA guidelines across the whole week (65%), with around 50% of children meeting guidelines over the weekend (51%). Similarly, on weekdays more than half of the children achieved 30 minutes within school (60%) while slightly less than 50% achieved 30 minutes out of school (48%). MVPA levels over the whole week reported in this study of 5 to 7-year-old children (Mean MVPA: 73.74 min, SD = 22.21) were higher than the MVPA levels observed in a large dataset of English children aged between 7 and 8 (Mean MVPA = 60.6 min) (Griffiths et al., 2013). This is in line with what is expected as 5 to 6 years old are generally more active than 7-8 years old children (Griffiths et al., 2013; Cooper et al., 2015). However, as shown in Supplementary material 10, the overall MVPA levels reported in this study for within school (Mean MVPA: 36.37 min, SD = 11.59 min) and out of school (Mean MVPA: 32.14 min, SD = 13.81 min) were lower than those reported in 7-11-year-old UK children during school (Boys: Mean MVPA = 46.1 min; Girls: Mean MVPA = 40.7 min) and after school (Boys: Mean MVPA = 49.4 min; Girls: Mean MVPA = 47.2 min) (McLellan et al., 2020). This could be due to the sample of the current study including children from deprived areas that might have limited PA experiences during school time as well as limited or no access to safe outdoor spaces at home or in the neighborhood, and low accessibility to community sports provision to be active out of school (Clennin et al., 2019). Nevertheless, the PA levels observed in this study during weekdays, weekend and in school (Weekdays: Mean MVPA = 76.91 min, SD = 22.92 min, weekend: Mean MVPA = 67.84 min, SD = 28.89 min), were very similar to the ones reported in a review summarizing objectively measured PA in school aged children from 4 to 18 (Weekday: mean MVPA = 82.3 min, SD = 44.0 min; Weekend: mean MVPA = 68.3 min, SD = 43.9 min; In school: mean MVPA = 34.4 min, SD = 14.6 min) (Brooke et al., 2014). Despite the fact that a large percentage of children in the current study met the PA guidelines, it was found that children's MVPA and mean ENMO declined from baseline to follow-up during the weekend. This is consistent with previous research showing that children's PA levels decline over time (Cooper et al., 2015) and suggests that interventions should focus on preventing the age-related decline in PA, particularly at weekends.

Similar to previous literature, it was found girls were consistently less active than boys (Deng and Fredriksen, 2018; McLellan et al., 2020); children with special educational needs were less active than other children (Hinckson and Curtis, 2013); white British children were generally more active than children from other ethnicity groups (Love et al., 2019a); BMI was negatively associated with PA levels (Owen et al., 2010); school sport events were associated with higher engagement in PA (Ridgers et al., 2005), and seasonal factors such as daylength and mean temperature were positively associated with PA, while rainfall was negatively associated with PA (Goodman et al., 2012; Harrison et al., 2017). The lack of an association between children's PA and neighborhood deprivation level could be due to the fact that the vast majority of the children in the current study were from deprived areas within the same deprivation decile. Nonetheless, findings from this study indicate that inequalities in PA levels are evident from an early age and that interventions should target subgroups for PA promotion including girls, black and ethnic minority groups, and overweight/obese children.

Based on the findings of the current study, future studies aiming at increasing PA or evaluating the effects of pedagogical approaches to PE in children within deprived areas should also find strategies to widen opportunities for children to be active. Researchers and practitioners should therefore consider a whole school and community approach where also parents and schoolteachers are involved to create better opportunities for children to be active within and outside school together with appropriate and rich educational experiences during PE hours (Castelli et al., 2014; Daly-Smith et al., 2020). In particular, for children living in deprived areas, researchers and practitioners should consider the challenges faced by schools and families and should design solutions to overcome problems in this specific population. For example, training school-teachers to deliver pedagogical approaches might be a more cost effective way for schools to provide PE interventions rather than paying external coaches. Furthermore, trained school-teachers could feasibly apply pedagogical principles outside PE such as during playtime, during after school activities or during school sport event and they could more easily provide an intervention for the entire duration of a school year. Moreover, school-teachers have a closer relationship with parents compared with external coaches and might inform them about the importance of providing children with increased PA opportunities.

Strengths and limitations

This study presented several strengths comprising the inclusion of device-based measurement of PA; the use of novel, comparable, and easy to interpret raw acceleration metrics; the inclusion of at least 3 week days and one weekend day as a valid week criteria to guarantee that PA assessment in this study is representative of children's normal PA levels over the whole week; the inclusion of a fidelity assessment to check that interventions were delivered as expected; the presence of both imputed data and complete case analysis to better interpret the outcomes of this study; and finally accounting for a wide number of covariates including weather and seasonal variation effects on PA. Furthermore, based on a thorough research, this study was the first to assess the effect of different pedagogical approaches based on movement learning theories on PA and the first study in 5-7-year-old children assessing the effects of PE interventions using device-based measures. This study also has some limitations such as the presence of 39% missing data within PA variables due to children moving to another school, dropping out from the study, not wearing the monitor enough to obtain a valid a PA measurement, or losing the accelerometer during the assessment period. However, the amount of missing data reported in this in this study is similar to that reported in previous research using device-based measurement of PA (Riiser et al., 2020; Vandelanotte et al., 2020). A further limitation is that most of the children did not wear the monitor overnight and that there was low compliance from parents with filling in PA wear time diaries leading to the impossibility to calculate waking time for each individual.

Conclusion and future directions

This study suggests that PE interventions based on Linear and Nonlinear pedagogy are not sufficient to increase PA levels in 5-6 years old children compared to common practice.

Possible explanations for a lack of an intervention effect could be the short duration of the intervention, the low of autonomy of children in this age group over their spare time (Huberty et al., 2012; Xu et al., 2015) and the lack of actions to target barriers to PA engagement (Beets et al., 2016). Therefore, future research should consider implementing strategies to increase occasions for children to apply the movement skills learnt during PE as well as enhanced PE sessions guided by pedagogical approaches. Furthermore, practitioners should consider more holistic approaches to supplement pedagogical approaches such as whole school programs of PA promotion and multi-component interventions targeting home and community settings to increase PA in children where teachers and parents present an active role in creating opportunities for children to practice movement skills and be active. In particular, training school-teachers to provide pedagogical interventions in PE could be a cost effective and viable option to increase the amount of time children are exposed to the pedagogical approaches and potentially might lead to increased occasions for children to be active in schools, might facilitate providing interventions for longer periods of time and could facilitate informing parents about the importance of providing children with occasions to be active.

Chapter 7: Synthesis

Introduction to the chapter

This chapter summarises the aims, outcomes, strengths, and limitations of the studies presented in this thesis. Furthermore, the chapter includes a discussion of findings underlining their implications and relevance for future research and practice in the field of PE. The last section of the chapter includes a personal reflection about my PhD journey.

Thesis summary

The overarching aim of this PhD thesis was to examine how PE pedagogies (i.e. Linear and Nonlinear), underpinned by movement learning theories, affect early primary school children's PA during PE and influence their habitual PA levels. In order to address this main aim, it was necessary to utilise a valid and reliable method to assess PA in 5-7-year-old children. ActiGraph accelerometer monitors provide valid and reliable measures of PA in older children and adults (Kim et al., 2012; Hildebrand et al., 2014, 2017). To date, no studies had calibrated GT9X ActiGraph devices for the assessment of PA intensities in 5-7-year-old children and no raw acceleration cut-points for ActiGraph devices have been developed in 5-6 years old children. Therefore, the first study of this thesis (Chapter 3) aimed to validate PA and SB raw ActiGraph GT9X accelerometer cut-points for the hip and wrist in 5-7-year-old children and compare the accuracy of hip and wrist placement. The findings suggested that raw acceleration cut-points presented acceptable validity and reliability for hip, dominant wrist and nondominant wrist placement to assess SB, LPA, MPA and VPA in 5-7 year old children (Crotti et al., 2020). Furthermore, LPA, MPA and VPA measurement presented higher accuracy compared to cut-points validated in other studies to assess PA in children (Hildebrand et al., 2014; Schaefer et al., 2014; Van Loo et al., 2018; Crotti et al., 2020). No conclusive evidence was found to suggest that one of the accelerometer wear positions, comprising hip, dominant wrist or nondominant wrist, could lead to more accurate estimates of PA and SB compared to the other placements (Crotti et al., 2020).

Given that teaching practices are a key determinant of children's engagement in PE (Weaver et al., 2016; Fairclough et al., 2018), a method to assess teaching practices associated with PA promotion was also needed. However, the modified version of the SOFIT+ had not been validated in children younger than 6-years-old nor amongst primary school aged children from countries outside of the USA (Weaver et al., 2016). Furthermore, SOFIT+ was not designed to capture aspects of Linear and Nonlinear pedagogy that may influence PA in PE. Consequently, the aim of the second study (Chapter 4) was to investigate the validity and reliability of a modified version of the SOFIT+ in 5-6-year-old children from Northwest England. The modified version of the SOFIT+ demonstrated to be a valid and reliable tool to assess teaching practices associated with PA in 5-6 years old children in UK (Crotti et al., 2021a). The new SOFIT+ teaching variables included in this thesis comprising *Discovery Practice*, *Instructs Class*, *Instructs Group*, *Instructs Single Child* and *Large sided PA* were generally associated with children's PA in the expected directions (Crotti et al., 2021a). Additionally, study 2 was the first SOFIT+ validation study to evaluate the association between SOFIT+ *Activity Management* variables. As a result, the *Activity Management* teaching practices comprising *Signalling*, *Retrieving equipment from one access point*, *Interruption Public*, and *Interruption Private* observed in study 2 were generally associated with poor children's PA engagement during PE (Crotti et al., 2021a).

The assessment tools developed in study 1 (i.e. accelerometer cut-points) and 2 (i.e. SOFIT+) were found to be reliable and valid and were therefore employed within the third (Chapter 5) and fourth study (Chapter 6) of the thesis, each conducted as part of the SAMPLE-PE project process and impact evaluations, respectively. Study 3 assessed 5-6-year-old children's MVPA and examined teaching practices associated with PA in PE lessons within

Linear pedagogy and Nonlinear pedagogy, compared to children participating in their standard PE curriculum in primary schools (control condition). The main findings revealed that PE interventions guided by Linear pedagogy and Nonlinear pedagogy interventions were not associated with differences in children's MVPA during PE compared to each other and compared to the control group, when controlling for variables associated with PA in PE (e.g. sex, age, lesson content) and when including children, schools and teachers as nesting factors in the statistical analyses. Results from the unadjusted teaching practices analysis suggested that Linear and Nonlinear pedagogical approaches presented a higher incidence of PA promoting teaching practices associated with children's MVPA in PE (e.g. *Motor content*, *Skill Practice*, *Discovery Practice*, *Individual Activity*, *PA Engaged*) and lower incidence of MVPA decreasing teaching practices (e.g. *Knowledge*, *Management*, *Instructs Class*, *Off Task*), compared to current teaching practices in PE lessons observed in the control group.

The final and fourth study of the thesis (Chapter 6) evaluated the effect of Linear and Nonlinear pedagogy PE interventions on the PA levels of 5–6-year-old children, compared to current practice within PE delivery in primary schools. Linear pedagogy or Nonlinear pedagogy PE interventions did not lead to increased habitual PA in children compared to those children participating in the control group PE lessons. A lack of intervention effect was generally observed across all the PA metrics studied and over different segments of the week comprising the whole week, weekend, weekday time in school and weekday time outside of school.

Discussion of main findings

Study 1. Physical activity measurement in children

The nondominant wrist accelerometers cut-points developed in study 1 were used within study 2, 3 and 4 in thesis based on previous research suggesting that wrist worn monitors generally lead to better wear compliance in children (Fairclough et al., 2016).

In study 1, novel methods to develop accelerometer cut-points were compared with commonly used accelerometer calibration procedures. More specifically, study 1 evaluated the accuracy of cut-points developed using different statistical analysis methods comprising the widely used Receiver Operating Characteristic (ROC) analysis "Youden" method and the novel ROC analysis "Distance" method, that had not been used in previous calibration studies (Crotti et al., 2020). Furthermore, study 1 was the first accelerometer calibration study to use pairs of activity levels in ROC analysis (e.g. SB versus LPA) to identify cut-points and the first to compare this method with the standard use of grouped activities in ROC analysis (e.g. SB versus LPA, MPA and VPA) (Crotti et al., 2020). As a result, cut-points developed using the ROC analysis Distance and paired PA levels methods generally led to more accurate cut-points compared to the commonly used Youden method and grouped activity method (Crotti et al., 2020). Furthermore, study 1 was the first published study to date to use an equivalency analysis method to modify the cut-points obtained from ROC analysis and identify cut-points presenting a better accuracy in SB and PA assessment (Crotti et al., 2020). In view of this, the novel validation methodologies used in study 1 might inform the selection of appropriate methods to develop cut-points for the measurement of PA and SB in the future (Crotti et al., 2020). Accelerometer cut-points are likely to remain a widely used method to measure PA in the future as they provide a PA outcome that can be easily interpreted based on current PA guidelines (e.g. time spent in MVPA) (Loprinzi and Cardinal, 2011; Aparicio-Ugarriza et al., 2015; Chaput et al., 2020).

Raw acceleration cut-points represents a great advancement towards transparency and harmonisation of PA assessment methods compared to proprietary counts based cut-points as raw accelerations signals should not incorporate brand specific signal processing before data are stored (van Hees et al., 2016). Nevertheless, recent studies showed that using a set of cut-points and accelerometer devices from a specific brand to assess PA in children could lead to PA estimates (i.e. SB, LPA, MPA and VPA) that are not equivalent to the ones obtained using different cut-points or different accelerometer brands (Van Loo et al., 2017, 2018; Rowlands et al., 2018b). Consequently, using different raw acceleration cut-points could potentially lead to contrasting results in terms of children meeting or not meeting PA guidelines (Rowlands, 2020). To tackle this problem, future research should compare the accuracy of different accelerometer cut-points and related accelerometer brands in measuring PA levels (Rowlands, 2020). This could be done by using multiple raw acceleration cut-points and accelerometer brands simultaneously to measure PA levels in children performing a wide variety of PAs and evaluating raw acceleration cut-points accuracy using PA observation tools or indirect calorimetry as criterion reference. Additionally, few studies reported that accelerometer devices developed by different brands or different accelerometer models within the same brand can lead to slightly different raw accelerations signals when measuring the same individuals simultaneously (Rowlands et al., 2018b; Clevenger et al., 2020). This suggest that more research is needed to evaluate and quantify the differences between accelerometer brands and models in terms of raw acceleration outputs to ensure comparability of raw acceleration data in future research (Rowlands, 2020).

Study 1. Future implications

The raw accelerometer cut-points developed in study 1 could be used by other researchers to assess SB and PA in 5-7 years old children using either hip or wrist GT9X

ActiGraph accelerometers (Crotti et al., 2020). Furthermore, the accelerometer validation methods used in study 1 could inform the validation of other accelerometers as well as the creation of cut-points for different age groups or the validation of tools to measure constructs that are different from PA (Crotti et al., 2020). The main methodological suggestions for future accelerometer validation studies derived from study 1 concerned the inclusion of paired activity levels analysis and distance method in ROC curve analysis together with the commonly used Youden ROC curve analysis as well as equivalency analysis and Cohen's Kappa statistic to select the most accurate SB and PA cut-points (Crotti et al., 2020). Furthermore, future cut-points validation studies should include PA measurement during free living conditions rather than laboratory based protocols to increase ecological validity in line with the methodologies proposed in study 1 (Crotti et al., 2020) Future research should also compare the accuracy of different raw acceleration cut-points in measuring PA levels in children (Rowlands, 2020). Additionally, more research is warranted to evaluate and quantify the differences between accelerometer brands and models in terms of raw acceleration outputs to facilitate comparability of PA measurements based on raw acceleration data in future research (Rowlands, 2020).

Study 2. Assessment of teaching practices associated with physical activity in physical education

This thesis validated a modified version of the SOFIT+ within study 2 (chapter 4). Compared to previous SOFIT+ validation studies (Weaver et al., 2016; Fairclough et al., 2018), Study 2 presented more advanced statistical analysis models allowing to assess the association between each teaching variable and children's MVPA, while controlling for other teaching practice variables. This is an important improvement from the previous validation studies as multiple teaching practices are observed within each SOFIT+ scan, consistent with the idea of teaching practices taking place simultaneously in the classroom (Doyle, 2015) and interacting to determine children's PA engagement. Therefore, the results from study 2 should provide a more accurate estimation of the association between teaching practices and MVPA in PE compared with previous studies (Weaver et al., 2016; Fairclough et al., 2018). Furthermore, different teaching variables were included in the SOFIT+ version validated in study 2. Based on Nonlinear pedagogy and Mosston production teaching styles *Discovery Practice* was added as a *Lesson Context* within the SOFIT+ (Crotti et al., 2021a). Supervising" was added within the Teaching Behaviour SOFIT+ category to code time where teacher observes teachers without interacting with them (Crotti et al., 2021a). The SOFIT+ variable "Instruction" was divided within '*Instructs Single Child*', '*Instructs Group*' and '*Instructs Class*' as the instruction of an individual or group should have a lower impact on decreasing MVPA during PE compared to instructing the whole class (Dale, 1991; Nicaise et al., 2007; Crotti et al., 2021a). And lastly "*Large Sided Activity*' was included within *Activity Context* category as this type of activity is representative of team invasion games and could lead to high MVPA engagement in PE (Tanaka et al., 2018; Crotti et al., 2021a). Results from study 2 Showed that teaching practices variables were generally associated with MVPA in PE in the directions expected (Crotti et al., 2021a). As concerns the novel SOFIT+ variables evaluated in study 2, *Discovery Practice* was associated with increased children's MVPA in PE compared to *Knowledge* time while *Supervising*, *Instructs Single Child*, *Instructs Group* were associated with higher levels of children's MVPA in PE compared to *Instructs Class* in line with what hypothesised (Crotti et al., 2021a). As concerns *Activity Management*, *Signalling* (e.g. asking the class to stop a ask) and *Retrieving equipment from one access point* were not strongly associated with increased children's MVPA in PE while interrupting the class was associated with decreased MVPA (Crotti et al., 2021a). Lastly Interrupting privately (e.g. addressing a single child misbehaviour) was not associated with decreased MVPA possibly because this practices did not affect MVPA level in the rest of the class that was not addressed by the teacher (Crotti et al., 2021a). In conclusion, SOFIT+ demonstrated to be a valid and reliable tool to assess Teaching practices associated with MVPA during PE in 5-6 tears old children from UK (Crotti et al., 2021a). Therefore, SOFIT+ could be a valuable tool for either teachers, researchers or coaches to asses teaching practices to increase children MVPA (Crotti et al., 2021a).

The SOFIT+ observation protocol (i.e. partial interval recording observation tactic using an observe and record format divided into 2 phases where phase 1 concerns *Lesson Context* and *Activity Context* assessment while phase 2 concerns *Teacher Behaviours* and *Activity Management* assessment. Each observation phase lasts 20 s, divided into 10 s of observation and 10 s of coding for a total duration of 40 s per scan) presents features that might negatively affect the accuracy of teaching practices assessment (Crotti et al., 2021a). More specifically, when using SOFIT+ researchers can observe only 50% of PE lesson time due to the 10 s observe and 10 s record format (Crotti et al., 2021a). Furthermore, researchers can assess each teaching practice over 10 s only during each 40 s of SOFIT+ scan due to the observation protocol being divided in 2 phases (i.e. phase 1 concerns *Lesson Context* and *Activity Context* assessment, while phase 2 concerns *Teacher Behaviours* and *Activity Management* assessment) (Crotti et al., 2021a). This observation format could potentially lead to a decreased accuracy in teaching practices assessment compared to observing and analysing 100% of PE lesson time using video recordings (McKenzie and Mars, 2015). Therefore, future research could evaluate the effects of different direct observation tactics on teaching practice assessment accuracy.

Study 2. Future implications

The modified SOFIT+ observation tool (Crotti et al., 2021a) could be used by researchers to assess interventions to increase MVPA in PE, to monitor teaching practices in PE, and to evaluate the effect of teacher training on teacher PA promoting behaviours (Crotti et al., 2021a). The methods used in study 2 could also inform future studies aiming at validating observation tools. In particular, results from study 2 suggest that future validation studies should find strategies to make sure that all the variables of interest are observed consistently during the data collection period (Crotti et al., 2021a). For example by designing PE lessons including all the teaching variables of interest rather than observing PE lessons where the PE deliverer is unaware of the aim of the study (Crotti et al., 2021a).

Future research should also investigate and compare different direct observation tactics to maximise the accuracy of the assessment of teaching practices associated with PA in PE. For example for teaching practices that are naturally continuous such as *Game Play* the observer could record the duration of each teaching practice over each 40 s observation scan using interval recording and duration recording tactics while for short-duration events such as *Signalling* or *Promotes PA* researchers could employ event recording tactics.

SOFIT+ can be a useful tool for practitioners to monitor teaching practices in PE and to reflect on their own teaching practices in order to improve their current MVPA delivery in PE (Crotti et al., 2021a). SOFIT+ validation study also provided practical indications about teaching practices that should be maximised or reduced in order to foster MVPA in PE that need to be disseminated to the field. For example, *Game Play* was the lesson content teaching practice associated with the highest levels of children's MVPA. This suggested that teachers should include *Game Play* as a teaching practice to both promote MVPA and movement competences during PE (Miller et al., 2015). Additionally, teachers should find strategies to increase MVPA in other *Lesson Contexts* (e.g. *Skill Practice*, *Discovery Practice*). Conversely, activities including children waiting for their turn to participate or elimination activities were associated with decreased children's PA, suggesting that these kind of activities should be minimised in PE to promote children's MVPA.

Study 3. Physical education pedagogies and physical activity during physical education

Children need to engage in PA to practice and develop their movement competences and PE is a key occasion for children to both engage in MVPA and increase their movement skills (Gallahue et al., 2012; Engel et al., 2018). The fact that Linear and Nonlinear pedagogy were not associated with increased MVPA in PE compared to current practice in PE (control group) could be due to the interventions being focused on movement competence development and fidelity to pedagogical principles rather than maximising PA engagement in children (Rudd et al., 2020a; Crotti et al., 2021b). Accordingly, the results from study 3 suggested that Linear and Nonlinear pedagogy PE interventions presented higher percentages of time spent in movement competence development activities (*Motor Content*) compared to the control group, but this did not translate into group differences in MVPA (Crotti et al., 2021b). Possible explanations for this could be that some of the movement competence activities within the intervention groups were not leading to high MVPA levels in children, with the increased *Motor Content* time not being sufficient to foster a significant increase in children's MVPA. The majority of previous PE interventions reporting increased children's MVPA levels compared to control conditions were delivered by PE specialists or teachers who were trained to use targeted teaching strategies to increase MVPA during PE such as: reducing time sitting and standing, promoting PA verbally (e.g. teacher encouraging students to do their best within a task), delivering high intensity activities, reducing time off task (e.g. making sure that all children participate in the task actively), decreasing elimination or waiting activities, and increasing time in game activities (McKenzie et al., 1996; Sallis et al., 1997; Coleman et al., 2005; Fairclough and Stratton, 2005; Logan et al., 2015; Powell et al., 2016, 2020; Telford et al., 2016; Weaver et al., 2017, 2018a). Importantly, within study 3 teachers accounted for approximatively a third of the MVPA variance reported in the multilevel models (ICC: 0.30-0.35) (Hoffman, 2019) confirming that teachers play a central role in determining children's MVPA during PE. Thus, future Linear and Nonlinear pedagogy interventions aiming at improving MVPA in PE compared to current practice in PE should consider training PE deliverers to maximise MVPA promoting teaching strategies (e.g. *Motor Content* and PA Promotion) and decrease MVPA reducing teaching strategies (e.g. decreasing Instruction time and waiting activities). This should be done as promoting more PA opportunities can lead to greater movement learning possibilities for children.

Study 3 also found that, compared to the control group, the Linear pedagogy intervention presented higher incidence of MVPA promoting teaching practices including time spent in *Motor Content* and teachers engaging in PA with children, as well as decreased incidence in MVPA reducing practices, such as time spent in *Management*. However, Linear pedagogy intervention presented lower percentage of *Game Play* within PE lessons compared to the control group, and this is important as *Game Play* was found to be associated with the highest MVPA engagement in PE compared to other type of *Lesson Contexts* (Crotti, Rudd, Weaver, et al., 2021; Tanaka et al., 2018; R. Glenn Weaver et al., 2016). Furthermore, Linear pedagogy intervention was also associated with a higher percentage of children being off task (time when one or more students are not engaged in the task proposed by the teacher) compared to the control group, which has negative implications for MVPA (Weaver et al., 2016; Crotti et al., 2021a) and also for other PE learning outcomes. Therefore, future interventions guided by Linear pedagogy should consider increasing the proportion of *Game Play* tasks focused on movement competence development and decrease *Children Off Task* within PE (Wood and Hall, 2015; Tanaka et al., 2018). Similar to the Linear pedagogy intervention, the Nonlinear intervention group presented higher proportion of MVPA promoting practices (i.e. *Motor Content*) compared to the control group. Furthermore, the Nonlinear group presented a lower incidence of several PA decreasing teaching practices comprising *Knowledge*, *Management*, *Waiting Activity*, *Elimination Activity* and *Instructs Class* and teacher being *Off Task*, compared to the control group. Yet, compared to the control group, Nonlinear pedagogy intervention presented a higher incidence of *Children Off Task* (associated with decreased MVPA in PE) while teachers never engaged in PA with students, which is considered an MVPA promoting teaching practice. Given that Nonlinear intervention generally presented lower percentages of MVPA decreasing teaching practices compared to the control group, future Nonlinear pedagogy interventions might focus on improving aspects of MVPA promoting teaching practices in PE (Weaver et al., 2016; Fairclough et al., 2018; Crotti et al., 2021a). For example, teachers could participate in PE as an active constraint to promote MVPA engagement or could promote MVPA engagement verbally or could design activities specifically focusing on affordances that lead to high MVPA engagement. In particular, both Linear and Nonlinear intervention presented none or very low incidence of verbal promotion of PA engagement suggesting that this aspect could be improved in future PE interventions. Maximising MVPA engagement during *Motor Content* in PE might also have a positive effect on movement learning as by engaging in high MVPA levels children would have more opportunities to explore and practice movement skills (Gallahue et al., 2012; Engel et al., 2018).

The children participating in the SAMPLE-PE project (aged 5-6 years between January 2018 and July 2018) found themselves within the *Preoperational Stage* (between 2-6years of age) of cognitive development described by Piaget (Piaget, 1969; Kushner et al., 2015). Children within the *Preoperational stage* generally present the following characteristics: they are egocentric (i.e. they generally prioritize their own needs and desires over the interests and desires of others); “play and pretend” activities represent a key way to learn and explore the world for them; and lastly they might lack the ability to process complex information in a logical way (Piaget, 1969; Pellegrini et al., 2007; Kushner et al., 2015; Tomporowski et al., 2015). Nonlinear pedagogy could potentially be more appropriate than Linear pedagogy to deal with the mentioned children's characteristics during the *Preoperational* cognitive stage for multiple reasons. Firstly, Nonlinear pedagogy would be an optimal approach to deal with children's egocentrism as it would provide children with more autonomy over activities and equipment used during PE (Chow, 2013; Atencio et al., 2014). For example, *Discovery Practice* represents a key teaching practice to foster autonomy in movement exploration during PE and it was only observed in Nonlinear pedagogy within study 3. Secondly, as observed in study 3, Nonlinear pedagogy should involve more *Game Play* and *Discovery Practice* activities compared to Linear pedagogy that are more in line with "play and pretend" activities compared to the *Skill Practice* drill-based activities observed in Linear pedagogy (Pellegrini et al., 2007; Chow, 2013). Lastly, Nonlinear pedagogy should minimise the amount of complex information provided to the children in terms of verbal explanations, as suggested by the lower incidence of *Instructs Class* observed in Nonlinear pedagogy compared to Linear pedagogy within study 3 (Correia et al., 2019; Rudd et al., 2020a). Furthermore, within a Nonlinear pedagogy approach learning should emerge by the interaction between individual and environment in a movement perception action coupling and teachers should modify individual, task and environmental constraints to channel movement skills learning rather than provide instructions and demonstrations (Chow, 2013). Despite the potential advantages associated with Nonlinear pedagogy in this 5-6 years old children, educators should carefully select pedagogical approaches in PE based on numerous factors such as lesson aims, children's characteristics, children's previous experiences or preferences and other contextual factors such as space and equipment in order to design quality PE experiences for learners (Ennis, 2017).

Given that no previous study to date has reported MVPA during PE using accelerometers specifically in 5-6-year-old children, the MVPA data presented in study 3 (Chapter 5) provides valuable information about MVPA in this age group. Within study 3, the standard PE curriculum was delivered by either class teachers, coaches or PE specialists, while trained coachers delivered Nonlinear and Linear PE interventions. As a result, on average, children within the control group engaged in MVPA for 29.1% (± 11.4%) of PE time, while Linear and Nonlinear interventions reported an average MVPA% equal to 35.1% (±10.1) and 38.4% (±10.9), respectively. The mean MVPA% of the control group was similar or higher to previous studies where PE was provided by generalist class teachers, with mean accelerometer determined MVPA% ranging from 9.5% to 29.7% among children aged between 6 and 11 years (Nettlefold et al., 2011; Wood and Hall, 2015; Tanaka et al., 2018). This could be due to the control group PE deliverers including generalist teachers and sports coaches as well as PE specialists. In fact, PE specialists generally engage children in higher MVPA levels compared to generalist teachers (McKenzie et al., 1993, 1995, 1997; Telford et al., 2016). Interestingly, the mean MVPA% observed in Linear (Girls: 33.4%, Boys: 37.3%) and Nonlinear intervention (Girls: 36.9%, Boys: 39.0%) in study 3 was similar to the MVPA% observed in PE interventions targeting PA including PE specialists and 6-9 years old children (Girls: 26.6%, Boys: 39.0%) (Weaver et al., 2017). Nevertheless, the fact that MVPA% recorded in study 3 was consistently lower than 50% in intervention and control groups is in line with the vast majority of previous research assessing children's MVPA in PE (Fairclough and Stratton, 2006; Hollis et al., 2016), suggesting that more should be done to increase children's MVPA in PE. Consistent with previous literature, Study 3 reported that a wide range of other factors were associated with children's MVPA levels in PE including sex, lesson duration, lesson content and lesson location (Costa et al., 2016; Kwon et al., 2020; Tanaka et al., 2020). In light of this, future research should account for these factors when designing PE interventions to promote

PA in PE, but also when designing statistical models to analyse the effectiveness of PE interventions on MVPA outcomes.

Study 3. Future implications

Study 3 suggested that by Linear pedagogy and Nonlinear pedagogy were not leading to increased MVPA in PE in 5-6 years old children. Therefore, future researchers aiming to implement Linear and Nonlinear interventions in young children as well as to increase MVPA in PE should consider including strategies to increase MVPA promoting teaching practices and reduce MVPA decreasing teaching practices in PE to obtain significant intervention effects on MVPA during PE. In turn, fostering children's MVPA engagement during movement learning activities should expand their opportunities to improve movement skills.

Furthermore, the results from study 3 suggested that teachers employing PE pedagogies focused on movement competence development in children such as Linear and Nonlinear pedagogy could significantly increase *Motor Content* time in PE and potentially improve movement competences in young children without decreasing children's PA levels during PE compared to current practice in PE. This would be important as improving movement competence could in turn enhance children's actual and perceived capability to engage in wide variety of PAs, sports and recreational opportunities (Hulteen et al., 2018). Additionally, PE practitioners should consider employing Nonlinear pedagogy when teaching children within their *Preoperational* cognitive stage (2-6 years of age) as this pedagogical approach would be highly appropriate to deal with children's characteristics and needs in this age group (e.g. egocentrism).

In line with the vast majority of previous research assessing children's MVPA in PE (Fairclough and Stratton, 2006; Hollis et al., 2016) MVPA% recorded in study 3 was lower than 50% in all groups. This suggests that policy makers should increase the focus on engaging students in MVPA over at least 50% of PE lesson time (Pate et al., 2006; AAHPERD, 2013; afPE, 2020) for example by publishing guidelines and reports about the advantages of increasing MVPA during PE for children development.

Lastly, In agreement with previous research, study 3 showed that teachers are a key predictor of children's MVPA (McKenzie et al., 1993, 1995, 1997; Telford et al., 2016). More specifically, previous research suggested that PE specialists are more effective in improving children's MVPA during PE compared to less experienced teachers (e.g. generalist teachers) (McKenzie et al., 1993, 1995, 1997; Telford et al., 2016). Currently, in the UK, primary PE education is often delivered by either generalist teachers or externally hired multi-sport coaches rather than by PE specialists (Griggs, 2016). In view of this, future policies should guarantee that primary PE education will be delivered by PE specialists in the future. Alternatively, the generalist teachers responsible for PE delivery should demonstrate the knowledge and understanding necessary to deliver quality PE and/or should periodically participate to compulsory trainings concerning PE teaching.

Study 4. Physical education pedagogies and habitual physical activity

Study 4 found that Linear and Nonlinear pedagogy SAMPLE-PE interventions did not lead to increased PA compared to participation in the standard PE curriculum (control group) in primary school children. The lack of intervention effect was generally consistent across all PA metrics (i.e. MVPA, mean raw acceleration, lowest acceleration over the most active hour, lowest acceleration over the most active half an hour) and time segments (whole week, weekend, weekday in school and weekday outside of school). The lack of Linear and Nonlinear pedagogy intervention effect on PA outcomes is consistent with the findings from study 3 where Linear and Nonlinear interventions were not associated with increased MVPA in children. This suggests that interventions focused on movement competence development and fidelity to pedagogical principles rather than promoting habitual PA in children might not be enough to change PA in children.

Furthermore, results from study 4 are in line with previous research examining the effects of PE interventions on children's habitual PA using device-based methods (Sallis et al., 1997; Caballero et al., 2003; Verstraete et al., 2007a; Telford et al., 2016). Conversely, the findings from study 4 are in contrast to studies employing self-report or parent proxy measures, which have generally found that PE interventions increased habitual PA levels (Manios et al., 1998; Caballero et al., 2003; Verstraete et al., 2007a; Boyle-Holmes et al., 2010; Sacchetti et al., 2013; Invernizzi et al., 2019). Nevertheless, results from studies employing self- or parent-proxy reported PA measurement should be interpreted cautiously due to factors such as recall bias, social desirability bias and the difficulty for children in classifying PA intensities leading to poor and biased estimate of PA especially in children (Warren et al., 2010; Hidding et al., 2018). Despite the lack of an intervention effect, study 4 found that PA was positively associated with factors such as participation in school sport week events (Ridgers et al., 2005) and daylight percentage and negatively related with rainfall (Goodman et al., 2012; Harrison et al., 2017). These findings suggest that children may be more active if they have more structured (e.g. sport) or unstructured (e.g. outdoor play time) PA opportunities to be active. Taken together, the results suggest that focusing on improving movement competence in children through Linear and Nonlinear PE approaches might not be sufficient to increase habitual PA if 5-6-year-old children are not provided with more and better quality occasions to be active, as well as necessary space and equipment, both at school and outside school in the home and community (Beets et al., 2016). A possible reason why Linear and Nonlinear interventions were not effective in modifying children's PA behaviours is that they mainly focused on movement competence development rather including intervention components addressing other important aspects of children's physical literacy development (Cairney et al., 2019). Many national institutions and researchers suggested that PE should focus on promoting affective, cognitive, physical capabilities and behavioural aspects of physical literacy in children as this could positively affect their PA trajectories and health (Edwards et al., 2017; Green et al., 2018; National Assembly for Wales, 2019; UK Department of Education, 2019; Shearer et al., 2021). In line with this, PE teachers could:

i) help children understanding the importance of PA for their health and happiness (e.g. by improving their knowledge and understanding about PA) (Cairney et al., 2019);

ii) help children exploring what is meaningful and motivating when engaging in PA (e.g. by working on affective, motivational and social aspects associated with PA) (Cairney et al., 2019);

iii) help children building skills to plan their personal journeys as physical literate individuals (e.g. by creating awareness about PA behaviours and improving their movement skills) (Cairney et al., 2019).

Pedagogical approaches to movement skills development such as Linear and Nonlinear pedagogies should still represent an important aspect of physical literacy development as improving movement competence would enhance children's actual and perceived capability to engage in PA potentially facilitating their physical literacy development (Stodden et al., 2008; Loprinzi et al., 2015; Robinson et al., 2015; Lima et al., 2017; Utesch et al., 2018). However, to date there is lack of research assessing strategies to improve physical literacy during PE and evaluating the relation between physical literacy development and PA (Liu and Chen, 2020).

Given that opportunities to engage in PA for young children are generally determined by adults (e.g. teachers or parents) and that interventions supporting parents in setting PA goals and PA time were generally effective in increasing children's PA (Brown et al., 2016), future school based interventions should consider engaging the parents in children's PA promotion.

Nevertheless, children and parents from deprived areas are in a disadvantaged situation compared to more wealthy families as children have limited access to safe playgrounds, unsafe streets due to traffic and crime safety of the area (Noonan et al., 2016; Chang and Kim, 2017), while parents have limited amount of time to support and participate in PA with children because of their work schedules and domestic responsibilities, as well as limited financial resources to afford PA opportunities such as sport opportunities for their children (Chang and Kim, 2017). Therefore, children from deprived areas would particularly benefit from improved and enhanced PA opportunities provided by the school such as increased playtime, in-class enhanced PA, quality PE and free opportunities to participate in after school PA programs. This is in line with a recent review reporting that multi-component interventions in school setting are more effective in promoting children's PA compared to interventions focusing on a single intervention component (e.g. PE) (Messing et al., 2019). Therefore, findings from study 4 and previous research suggest that enhanced quality PE guided by pedagogical approaches would need to be extended and supplemented by whole school approaches to PA promotion and multi-component interventions targeting home and community settings to increase PA in young children from deprived areas.

Study 4 (Chapter 6) measured habitual PA in 5-7 years old children (n = 360) from deprived areas and presented accelerometer wear compliance data together with reasons for missing PA data (see supplementary material 9). This information could be valuable for researchers intending to measure habitual PA in children within this population as it could help them to select the best strategies to maximise wear compliance and prevent data loss (Crotti et al., 2021b). Habitual PA was assessed using wrist-worn accelerometers for an entire week over 3 time points (before the intervention, after the intervention and 6 months after the end of the intervention). The PA inclusion criteria for study 4 were wearing the monitor for 10 hours during waketime and for 3 weekdays and one weekend day at least, respectively (Migueles et al., 2017). Within each measurement timepoint, the children who did not wear the monitors for at least 3 valid weekdays and 1 valid weekend day were invited to wear the accelerometer again for 7 days. At baseline, 72.8% (262 children) of participants presented a valid week PA measurement, while the percentage decreased to 58.1% (209) at post-intervention and to 50.2% (181) at follow up. The main reason for missing PA concerned children not meeting the wear time inclusion criteria (accounting for 66.5%-80.8% of missing data within the different assessment points), generally followed by the child being absent from school when accelerometers were issued, the child not wanting to wear the accelerometer, and finally, lost accelerometers. During post-intervention and follow-up assessment, a further reason for missing data concerned children moving to another school and this factor accounted for a significant proportion of missing PA data at follow-up (15.1%). Thanks to the re-monitoring strategy used in study 4 to increase the amount of valid PA data, the number of children presenting valid PA data at baseline from wrist-worn accelerometers in study 4 (72.8%) was higher than that observed in a study by Fairclough et al. (2016) involving 10-year-old children from deprived neighbourhoods who wore GENEActiv wrist and ActiGraph hip accelerometers for 7 days (68.2% of valid PA data using the same wear inclusion criteria). Therefore, in view of the compliance results obtained in the present study, future studies should consider including a re-monitoring phase to increase the proportion of valid PA data. Nevertheless, further strategies are needed to increase compliance in view of the general drop in valid PA data observed in post-intervention and follow-up phases in study 4 and in previous studies using accelerometers to assess habitual PA (Riiser et al., 2020; Vandelanotte et al., 2020). Previous research suggested that viable strategies to increase accelerometer wear compliance in children could be the use of sticky note reminders, mobile phone reminders to children’s guardians and social conformity strategies (McCann et al., 2016).

The overall MVPA levels during the whole week reported in study 4 comprising 5 to 7 year-old children (Mean MVPA: 73.7 min, SD = 22.2) were higher than the MVPA levels (Mean MVPA = 60.6 min) observed in a large dataset of 7-8 year-old children from England participating in the Millennium cohort study (Griffiths et al., 2013). Similarly, at baseline in Study 4 during winter (January and February 2018), 64.6% of the children met the PA guidelines across the whole week while previous research found that only 50.7% of the children from UK aged between 9 and 11 years met the PA guidelines (Roman-Viñas et al., 2016). This is in line with previous literature showing that 5- to 6-year-old children are generally more active than older children (Griffiths et al., 2013; Cooper et al., 2015). During all time points reported in study 4 (i.e. baseline, post-intervention and follow up) a higher proportion of children met the PA guidelines during the week (e.g. 70.0% at baseline) compared to the weekend (e.g. 51.0% at Baseline) suggesting that children are less active during the weekend, which is consistent with previous research (Ramirez-Rico et al., 2014; Noonan et al., 2017). Additionally, children's PA levels were higher during the summer months (June and July 2018) compared to the winter months (January and February 2018 and 2019) in both intervention and control groups, with 90.3% of children meeting the PA guidelines across the week and 73.0% over the weekend during summer months. These findings are consistent with previous research showing that children are more active during the summer (Rich et al., 2012) and supports the inclusion of variables in the study 4 analysis to account for seasonal factors, including daylight, mean temperature, and rainfall. Furthermore, a PA decline from baseline to follow-up (January-early March 2019) was observed during the weekend in line with previous research showing that children's PA levels decline over time (Cooper et al., 2015). This suggested that it is important to foster children's PA engagement since early childhood and strategies are needed to improve PA in children during weekend in particular.

Similar to previous literature, study 4 found that sex (Deng and Fredriksen, 2018), BMI (Owen et al., 2010), special educational needs (Hinckson and Curtis, 2013), ethnicity (Love et al., 2019a), sport events (Ridgers et al., 2005), rainfall, daylength and mean temperature (Goodman et al., 2012; Harrison et al., 2017) were associated with children's habitual PA. This suggests that future interventions aiming at increasing habitual PA should consider child characteristics and target populations that are particularly at risk of low engagement in PA. Furthermore, future studies assessing the effect of interventions on children's habitual PA should account for both individual characteristics and seasonal or environmental factors associated with PA in children as not doing so could lead to biased conclusions about intervention effects.

Lastly, the fourth study of this thesis was the first study to use PA metrics based on raw accelerations (i.e. MVPA, mean raw acceleration, lowest acceleration over the most active hour, lowest acceleration over the most active half an hour) to assess the effects of a PA interventions in children. It is likely that future studies examining PA will report both PA derived from raw acceleration cut-points as well as other raw acceleration metrics (e.g. mean raw acceleration) as reported in study 4 to facilitate the comparison of PA outcomes from different studies (Rowlands et al., 2018a, 2019; Fairclough et al., 2020). Raw acceleration metrics represents a huge advancement towards transparency in PA assessment methods and they should facilitate the comparison of results obtained by different accelerometer brands compared to using cut-points based on proprietary counts for PA assessment (van Hees et al., 2016). However, as reported in "Study 1. Physical activity measurement in children" section in this thesis, more research is needed to evaluate and quantify the differences between accelerometer brands and models in terms of raw acceleration outputs to ensure comparability of raw acceleration data in future research (Rowlands, 2020).

Study 4. Future implications

Study 4 suggested that by Linear pedagogy and Nonlinear pedagogy were not leading to increased habitual PA in 5-6 years old children. As for school-based interventions aiming at increasing habitual PA in children, future PE interventions guided by Linear and Nonlinear pedagogy should consider including extended opportunities for children to apply what learnt during PE, as well multiple approaches to PA promotion comprising home and community settings components with a particular focus on PA opportunities within school in children from deprived areas (Crotti et al., 2021b). Furthermore, future PE research should explore different strategies to promote physical literacy as well as movement competence development in children to foster positive changes in children's PA behaviours (Cairney et al., 2019).

The fact that interventions based on Linear and Nonlinear Pedagogies were not associated with increased PA compared to current practice in PE in UK could be due to young children having low autonomy over their PA opportunities outside PE lessons (Brown et al., 2016). Adolescents are more independent and present higher cognitive capacities compared to young children (Newton and Harrison, 2005; Casey et al., 2019) and therefore might have more autonomy in seeking for opportunities to be physically active. Nevertheless, adolescents are less active than children and therefore it is important to find strategies to increase PA in this population too (Farooq et al., 2018). Quality PE guided by Linear pedagogy or Nonlinear pedagogy might lead to a better satisfaction of psychological needs in adolescents comprising "competence" (e.g. feeling capable to participate in a sport or PA discipline), "autonomy" (e.g. feeling able to independently take action and engage in new PA occasion), and "relatedness" (i.e. feeling a connection with the peers participating in the same movement activity) compared to current practice in PE (Gunnell et al., 2016). The satisfaction of the mentioned psychological needs could positively affect children's motivation to seek for more occasion to be active

(Gunnell et al., 2016). Therefore, future studies should evaluate the effect of PE interventions guided by Linear and Nonlinear interventions on PA levels in adolescents.

This thesis only focused on quantitative aspects concerning PE intervention based on Linear and Nonlinear pedagogy and children PA engagement. Therefore, future studies should evaluate how Linear and Nonlinear intervention could affect the lived PA experiences in children from a qualitative perspective or a combination of qualitative and quantitative perspectives. In particular, future studies should explore how pedagogical approaches in PE might lead to meaningful experiences or foster the development of meaning associated with PA experiences in young people (Beni et al., 2017). Providing children meaningful experiences in PE might have an important impact on their future willingness to engage in PA during PE or in other PA experiences within and outside school (Beni et al., 2017). Lastly, another important focus of future qualitative research would be the effect of teacher trainings to deliver different PE pedagogies on their PE delivery and on their lived experiences within PE classes (Pascual, 2006). Collecting insights about teachers' personal development and meaningfulness in PE might help understand what is relevant and motivating for teachers to improve their PE delivery in the future.

As concerns assessment of habitual PA in children, future research should include strategies to maximise accelerometer wear time to obtain PA data that are representative of children's actual PA levels (e.g. including a re-monitoring phase to assess participants who did not wear the accelerometer enough) (Crotti et al., 2021b). Lastly, future research concerning habitual PA in children should include both cut-point based and cut-point free raw acceleration PA outcomes to facilitate the interpretation and comparison of results obtained in different studies (Crotti et al., 2021b).

Unique contributions to the literature

Study 1

- The identification and validation of raw acceleration cut-points for the dominant and non-dominant wrist as well as hip placement for GT9X ActiGraph accelerometers in 5-7 year-old children.
- The use of novel cut-point identification methods comprising paired activity levels and distance method within ROC analysis alongside equivalency testing, to select the most accurate cut-points.

Study 2

- The validation of a modified SOFIT+ in 5-6 year-old children.
- The cross-cultural validation of SOFIT+ in teachers/coaches and primary school children from the UK.
- The introduction and validation of the assessment of novel teaching practices within a modified SOFIT+: *Discovery practice*, *Supervises*, *Large Sided Activity*, *Instructs Class*, *Instructs Group*, *Instructs Single Child*.
- The evaluation of the association between *Activity Management* teaching practices (i.e. *Signalling*, *Retrieving equipment from one access point*, *Interruption Private*, *Interruption Public*) and children's MVPA in PE.

Study 3

- The assessment of children's MVPA during PE interventions guided by Linear Pedagogy and Nonlinear pedagogy and the comparison of children's PA within the aforementioned interventions with current practice in PE delivery within primary schools in UK.
- The assessment of teaching practices associated with MVPA promotion during PE interventions guided by Linear Pedagogy and Nonlinear pedagogy and the comparison

of teaching practices within the aforementioned interventions with current practice in PE delivery within primary schools in UK.

- Measuring and reporting MVPA minutes and MVPA% during PE using accelerometers in 5-6 years old children from deprived areas specifically.

Study 4

- The assessment of the effect of PE interventions guided by Linear and Nonlinear pedagogy on Children's PA during the whole week and different time segments of the week (i.e. during school, after school, during the weekend).
- The assessment of children's PA levels using both validated MVPA cut-points and raw accelerometer metrics (i.e. Average ENMO acceleration, lowest acceleration during the most active hour, lowest acceleration during the most active half an hour).

Strengths of this thesis

A major strength of this thesis is that the measurement methods developed in population-specific samples in study 1 and study 2 were employed in other studies within the thesis. More specifically, accelerometer cut-points developed in study 1 were used in study 2, study 3 and study 4 to assess MVPA in children. Furthermore, the SOFIT+ observation tool validated in study 2 was used in study 3 to assess teaching practices associated with children's MVPA in PE. A key strength of the accelerometer calibration study (study 1) was the inclusion of novel methodologies to improve the accuracy of PA assessment, the development of raw acceleration cut-points rather than count-based cut-points and the inclusion of multiple accelerometer placements. Furthermore, strengths of the SOFIT+ validation study comprise the inclusion of new variables within the tool and the use of children's MVPA levels during PE derived from accelerometers as the criterion reference. Another important strength of this thesis was that study 3 and study 4 were the first studies to investigate how PE interventions based on Linear pedagogy and Nonlinear pedagogy could affect MVPA in PE and habitual PA levels, respectively in children. Furthermore, an important strength of study 3 was that it measured both children's MVPA and teaching practices during the same PE lessons to help clarify the impact of teaching practices on children's MVPA during PE. As for study 4, a major strength was the inclusion of accelerometer-based measurement of habitual PA and the use of novel raw acceleration metrics that could facilitate the comparison of PA outcomes with other studies in the future. Lastly, methodological strengths of both study 3 and study 4 include the use of clustered randomised controlled trials and statistical models accounting for PA data being nested within child, teacher, and school as well as accounting for variables associated with PA in children.

Limitations of this thesis

A general limitation found across different studies in this thesis concerned aspects relative to the sample size selected for final analysis. More specifically, within study 1 it was not possible to complete all measurement in 17 participants that were consequently excluded from the final data analysis leading to a final sample of 32 children. In study 2 and study 3, due to time and feasibility constraints only 9 schools were included in the sample and only 50% of the children that provided consent to participate in the study were assessed, leading to a final subsample of 162 children instead of the total 360 children. As regards study 4, the number of children presenting valid PA measurement decreased from baseline to follow up where from a total of 360 participants 262 children presented valid PA data at baseline, 209 presented valid data post-intervention and 181 presented valid data at follow up. The reasons behind missing PA measurement comprised: moving to another school, dropping out from the study, not wearing the monitor enough to obtain a valid a PA measurement, or losing the accelerometer during the assessment period. Another limitation observed in study 3 and study 4 was the presence of missing data in more than one secondary variable comprising age, BMI, ethnicity, index of neighbourhood deprivation and information about special educational needs. To account for missing data, different strategies were employed in study 3 and 4 such as the exclusion of variables presenting missing data in case they did not increase the fit of the model in study 3, and the use of multiple imputation methods in study 4. A further limitation concerning data availability was observed in study 3 where due to the relatively low amount of lessons observed per teacher and per pedagogical group it was not possible to design statistical models accounting for observations being nested in schools and teachers and for covariates (e.g. lesson content) when analysing teaching practices associated with MVPA in PE.

Conclusions of this thesis

This thesis provides a unique contribution in evaluating how Linear and Nonlinear PE pedagogies underpinned by movement learning theories could influence MVPA during PE and habitual PA in children within the first year of primary school. This thesis includes the development PA assessment methods (raw acceleration cut-points for GT9X ActiGraph devices mounted on wither dominant or non-dominant wrist or on hip) and a teaching practices assessments tool (SOFIT+) that could be used by researchers and practitioners in the future. Additionally, the findings from this thesis suggest that implementing PE pedagogies whilst maintaining fidelity to Linear and Nonlinear pedagogy principles might not be enough to increase children's MVPA in PE of Habitual PA compared to current practice. Furthermore, the high incidence of MVPA promoting teaching practices (e.g. *Motor Content*) and low incidence of MVPA decreasing practices (e.g. *Management, Elimination Activity*) in Linear and Nonlinear pedagogy suggest that it could be possible to increase MVPA within lessons whilst maintaining pedagogical fidelity. In order to increase children's PA in PE interventions should implement strategies that are specifically focused on children's MVPA such as teacher training focusing on the implementation of MVPA promoting teaching practices (e.g. increasing *Motor Content* and *Game Play* as well as decreasing *Management* time and children being off task). Interventions aiming at improving habitual PA among young children in deprived areas should consider implementing multicomponent interventions including increased and enhanced opportunities for children to be active.

Personal reflection

This thesis is the culmination of a PhD Journey that made me grow both as a person and as a researcher form many different perspectives. Furthermore, the process of writing this thesis made me appreciate how much I had learned and achieved during my PhD work. It also confirmed to me that this would have been impossible without a great team of supervisors and colleagues within an inspiring and well organised work environment at Liverpool John Moores University.

I vastly improved my subject knowledge and understanding about pedagogies, PE, PA in children, PA interventions, PA measurement, movement competence, movement competence measurement, research design, and quantitative data analysis, amongst many other topics. This learning process was continually nurtured by discussions with supervisors and colleagues, by reading relevant scientific literature, and through participation in conferences and relevant courses. From a more practical perspective, I learnt very important skills within the field of PA assessment. More precisely, I had the chance to work with different types of accelerometers (even if in this study I only employed GT9X ActiGraph devices), I learnt how to use different software to analyse results obtained using accelerometers and the use of different acceleration metrics. Furthermore, the fact that my thesis included both validation of measurement tools and studies where these tools were applied helped me develop a deeper knowledge and understanding about the strengths and limitations of each assessment tool. For example, the validation of accelerometer cut-points made me appreciate the difficulty of capturing information that are reflective of the actual PA levels in real world everyday activities, but it also opened my eyes about how different methods of accelerometer validation could lead to massively different estimates of PA. Furthermore, I now have a deeper knowledge of the criteria that are needed to obtain good estimates of PA levels from accelerometer measurements (e.g. such as non-wear criteria, valid days and valid week criteria). Thanks to the data collection process in this thesis, I now fully appreciate how intensive and complex it is to plan and complete the PA measurement of children within a cluster randomised controlled trial using accelerometers. Furthermore, I have a practical understanding about strategies that should be used to foster wear compliance in children. Similarly to my experience in calibrating accelerometers, the validation of the SOFIT+ observation tool to assess teaching practices in PE made me appreciate how challenging it is to capture aspects of human behaviours while maintaining high reliability and how much rigorously designed methods are fundamental to obtain results that are consistent between observers and reflective of the construct assessed. Furthermore, I gained experience about how observation tools can be a time expensive method of assessment. In line with this, given that a great part of my PhD work was within the SAMPLE-PE project, I could appreciate the intricacy and challenges of implementing a cluster randomised controlled trial within schools and what strategies could help researchers and teachers collaborate to reach a common goal to promote children development and health. Taken together, the previously mentioned skills I acquired helped me to develop what is probably one of the most important skills that I could learn: the knowledge and understanding necessary to critically evaluate the strength of research evidence. In a world where we are bombarded with information and in a scientific landscape where the number of new publications is exponentially growing, building the knowledge necessary to critically filter evidence is of the utmost importance.

Thanks to the many opportunities I had to present my research to different audiences such as researchers, students, colleagues or people from the public; to courses offered within the LJMU university (such as the 3is teaching course); and thanks to the opportunity to be a guest lecturer, I vastly improved my communication and teaching skills. My writing skills have also improved drastically and mostly thanks to the valuable comments I received from my supervisors. My improvements in communication skills were particularly satisfying for me as English is not my first language.

As concerns other important personal skills I developed during my PhD, I worked on improving my capacities to manage high amounts of work, to organize my time efficiently, and lastly to collaborate constructively with my work colleagues. However, some of the most valuable personal skills that I was required to develop to complete this PhD were coping mechanisms to overcome high levels of stress, finding satisfaction in even small accomplishments, and accepting my limitations (both mental and physical).

Aside from aspects of my PhD work, living and working away from my home country (Italy) gave me the opportunity to immerse in different cultures and to interact with people from very different backgrounds. In fact, apart from working in UK, during my PhD I had an internship at Arnold School of Public Health at University of South Carolina (USA) and I worked with people from different countries. These experiences made me understand much more about myself and about my identity as a person and my identity as a citizen of a global community. Lastly, I had the unvaluable chance to meet extraordinary people that I will never forget and to spend unforgettable moments with them that will be cherished lifetime memories for me.

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Supplementary materials

Supplementary material 1. Gentile's taxonomy adapted (Adams, 1999)

Gentile's taxonomy		**Action function**			
		Body stability (body is still)		**Body transport (body is moving in the space)**	
Environmental context		**No manipulation (object are not involved)**	**Manipulation (object are involved)**	**No manipulation (object are not involved)**	**Manipulation (object are involved)**
Stationary (environment remains the same)	**No intertrial variability (every time same conditions)**	(Person is) Not moving around. No objects involved. Environment stationary. All trials are the same.	Not moving around. Objects involved. Environment stationary. All trials are the same.	Moving around. No objects involved. Environment stationary. All trials are the same.	Moving around. Objects involved. Environment stationary. All trials are the same.
	Intertrial variability (there is a change in conditions)	Not moving around. No objects involved. Environment stationary. All trials are different.	Not moving around. Objects involved. Environment stationary. All trials are different.	Moving around. No objects involved. Environment stationary. All trials are different.	Moving around. Objects involved. Environment stationary. All trials are different.
Motion (Environment changes dynamically)	**No intertrial variability (every time same conditions)**	Not moving around. No manipulation of objects. Environment changes. All trials are the same.	Not moving around. Objects involved. Environment changes. All trials are the same.	Moving around. No objects involved. Environment changes. All trials are the same.	Moving around. Objects involved. Environment changes. All trials are the same.
	Intertrial variability (there is a change in conditions)	Not moving around. No manipulation of objects. Environment changes. All trials are different.	Not moving around. Objects involved. Environment changes. All trials are different.	Moving around. No objects involved. Environment changes. All trials are different.	Moving around. Objects involved. Environment changes. All trials are different.

Supplementary material 2. Ethics certificate


CERTIFICATE Of COMPETENCY

Matteo Crotti has achieved the required standard in

RESEARCH ETHICS TRAINING

PRESENTED BY: Dave Harriss

ON THIS DAY: October 18, 2017

Supplementary material 3. Tables concerning cut-points and related measurement properties in study 1

Supplementary Table 1. Sedentary Behaviours (SB) cut-points and related measurement properties

Non-dominant wrist placement

Phase 1: SB cut-points for non-dominant wrist placement developed using ROC analysis

SB cases	Control cases	SB cases (a.u.)	Control cases (a.u.)	AUC (a.u.)	AUC 95% CI (a.u.)	Youden cut-point (m*g*)	Sn (%)	Sp (%)	CK (a.u.)	%Ag (%)	Distance cut-point (mg)	Sn (%)	Sp (%)	CK (a.u.)	%Ag (%)
SB	LPA, MPA, VPA.	30318	25177	0.859	0.855-0.862	71	92.2	65.9	0.59	80.3	51	86.4	70.0	0.57	79.0
SB	LPA excluding standing while watching TV, MPA, VPA	30318	19237	0.958	0.956-0.959	71	92.2	65.9	0.59	80.3	61	89.6	67.8	0.58	79.7
SB	LPA	30318	12345	0.721	0.72-0.727	18	65.3	83.5	0.48	73.5	18	65.3	83.5	0.48	73.5
SB	LPA excluding standing while watching TV	30318	6405	0.892	0.888-0.896	38	80.0	73.3	0.53	76.9	38	80.0	73.3	0.53	76.9

Phase 2: SB cut-point for non-dominant wrist placement developed using Equivalency analysis

SB cases	Control cases	SB cases (a.u.)	Control cases (a.u.)	Equivalency analysis Cut-point (m*g*)	Sn (%)	Sp (%)	CK (a.u.)	%Ag (%)
SB	LPA, MPA, VPA.	30318	25177	36	78.7	73.9	0.53	76.5

Dominant wrist placement

Phase 1: SB cut-points for dominant wrist placement developed using ROC analysis

SB cases	Control cases	SB cases (a.u.)	Control cases (a.u.)	AUC (a.u.)	AUC 95% CI (a.u.)	Youden cut-point (m*g*)	Sn (%)	Sp (%)	CK (a.u.)	%Ag (%)	Distance cut-point (mg)	Sn (%)	Sp (%)	CK (a.u.)	%Ag (%)
SB	LPA, MPA, VPA.	30318	25177	0.801	0.797-0.805	76	91.3	63.9	0.56	79.9	49	83.3	69.7	0.53	77.1
SB	LPA excluding standing while watching TV, MPA, VPA	30318	19237	0.943	0.941-0.945	66	89.1	65.9	0.56	78.6	62	88.0	66.7	0.56	78.4
SB	LPA	30318	12345	0.611	0.604-0.617	53	85.0	68.7	0.54	77.6	28	68.1	75.2	0.43	71.3
SB	LPA excluding standing while watching TV	30318	6405	0.861	0.856-0.866	45	81.3	70.7	0.52	76.5	42	79.4	71.4	0.51	75.8

Phase 2: SB cut-point for dominant wrist placement developed using Equivalency analysis

SB cases	Control cases	SB cases (a.u.)	Control cases (a.u.)	Equivalency analysis Cut-point (m*g*)	Sn (%)	Sp (%)	CK (a.u.)	%Ag (%)
SB	LPA, MPA, VPA.	30318	25177	39	77.2	72.1	0.49	74.9

Hip placement

Phase 1: SB cut-point for hip placement developed using ROC analysis

SB cases	Control cases	SB cases (a.u.)	Control cases (a.u.)	AUC (a.u.)	AUC 95% CI (a.u.)	Youden cut-point (m*g*)	Sn (%)	Sp (%)	CK (a.u.)	%Ag (%)	Distance cut-point (mg)	Sn (%)	Sp (%)	CK (a.u.)	%Ag (%)
SB	LPA, MPA, VPA.	30318	25177	0.841	0.837-0.844	47	99.1	61.8	0.63	82.2	23	83.3	73.5	0.57	79.8
SB	LPA excluding standing while watching TV, MPA, VPA	30318	19237	0.955	0.953-0.957	43	97.7	63.1	0.63	82.0	33	91.0	66.9	0.59	80.1
SB	LPA	30318	12345	0.689	0.682-0.695	23	83.3	73.6	0.57	79.8	11	66.3	80.3	0.46	72.2
SB	LPA excluding standing while watching TV	30318	6405	0.890	0.885-0.895	25	85.0	72.2	0.58	79.2	22	82.2	74.2	0.57	78.6

Phase 2: SB cut-point for hip placement developed using Equivalency analysis

SB cases	Control cases	SB cases (a.u.)	Control cases (a.u.)	Equivalency analysis Cut-point (m*g*)	Sn (%)	Sp (%)	CK (a.u.)	%Ag (%)
SB	LPA, MPA, VPA.	30318	25177	20	77.9	75.3	0.53	76.7

SB cases: Number of observations of SB where each observation corresponds to 1 second

Control cases: Number if observations not including SB where each observation corresponds to 1 second

a.u.: arbitrary units

AUC: Area under the curve

AUC 95% CI: AUC 95% confidence interval

Sn: Sensitivity

Sp: Specificity

CK: Cohen's Kappa

%Ag: Percentage of agreement

Supplementary Table 2. Light physical activity (LPA) cut-points and related variables

Non-dominant wrist placement

Phase 2: LPA cut-point for non-dominant wrist placement developed using Equivalency analysis

LPA cases	Control cases	LPA cases (a.u.)	Control cases (a.u.)	Equivalency analysis Cut-point (m*g*)	Sn (%)	Sp (%)	CK (a.u.)	%Ag (%)
LPA	SB, MPA,VPA	12345	43150	36-189	38.4	81.5	0.16	71

Dominant wrist placement

Phase 2: LPA cut-point for dominant wrist placement developed using Equivalency analysis

LPA cases	Control cases	LPA cases (a.u.)	Control cases (a.u.)	Equivalency analysis Cut-point (m*g*)	Sn (%)	Sp (%)	CK (a.u.)	%Ag (%)
LPA	SB, MPA,VPA	12345	43150	39-181	30.2	80.3	0.10	69.1

Hip placement

Phase 2: LPA cut-point for hip placement developed using Equivalency analysis

LPA cases	Control cases	LPA cases (a.u.)	Control cases (a.u.)	Equivalency analysis Cut-point (m*g*)	Sn (%)	Sp (%)	CK (a.u.)	%Ag (%)
LPA	SB, MPA,VPA	12345	43150	20-95	36.7	80.8	0.17	71

LPA cases: Number of observations of LPA where each observation corresponds to 1 second

Control cases: Number if observations not including LPA where each observation corresponds to 1 second

a.u.: arbitrary units

Sn: Sensitivity

Sp: Specificity

CK: Cohen's Kappa

%Ag: Percentage of agreement

Supplementary Table 3. Moderate physical activity (MPA) cut-points and related variables

Non-dominant wrist placement

Phase 2: MPA cut-point for non-dominant wrist placement devel0ped using Equivalency analysis

MPA cases	Control cases	MPA cases (a.u.)	Control cases (a.u.)	Equivalency analysis Cut-point (m*g*)	Sn (%)	Sp (%)	CK (a.u.)	%Ag (%)
MPA	SB, LPA,VPA	5059	50436	189-536	38.3	93.7	0.32	87.7

Dominant wrist placement

Phase 2: MPA cut-point for dominant wrist placement developed using Equivalency analysis

MPA cases	Control cases	MPA cases (a.u.)	Control cases (a.u.)	Equivalency analysis Cut-point (m*g*)	Sn (%)	Sp (%)	CK (a.u.)	%Ag (%)
MPA	SB, LPA,VPA	5059	50436	181-534	36.4	93.6	0.30	88.4

Hip placement

Phase 2: MPA cut-point for hip placement developed using Equivalency analysis

MPA cases	Control cases	MPA cases (a.u.)	Control cases (a.u.)	Equivalency analysis Cut-point (m*g*)	Sn (%)	Sp (%)	CK (a.u.)	%Ag (%)
MPA	SB, LPA,VPA	5059	50436	95-325	47.8	94.7	0.42	90.4

MPA cases: Number of observations of MPA where each observation corresponds to 1 second

Control cases: Number if observations not including MPA where each observation corresponds to 1 second

a.u.: arbitrary units

Sn: Sensitivity

Sp: Specificity

CK: Cohen's Kappa

%Ag: Percentage of agreement

Supplementary Table 4. Moderate to vigorous physical activity (MVPA) cut-points and related variables

Non-dominant wrist placement

Phase 1: MVPA cut-points for non-dominant wrist placement developed using ROC analysis

MVPA cases	Control cases	MVPA cases (a.u.)	Control cases (a.u.)	AUC (a.u.)	AUC 95% CI (a.u.)	Youden cut-point (m*g*)	Sn (%)	Sp (%)	CK (a.u.)	%Ag (%)	Distance cut-point (m*g*)	Sn (%)	Sp (%)	CK (a.u.)	%Ag (%)
MPA,VPA	SB, LPA	12832	42663	0.975	0.974-0.977	112	93.5	90.9	0.78	91.5	117	93.0	91.4	0.78	91.7
MPA,VPA	SB, LPA excluding standing watching TV	12832	36723	0.972	0.971-0.974	117	93.0	91.4	0.79	91.7	128	91.8	92.3	0.78	92.2
MPA	LPA	12832	5059	0.887	0.882-0.892	105	94.1	90.1	0.78	91.1	117	93.0	91.4	0.77	91.7
MPA	LPA excluding standing watching TV	6405	5059	0.793	0.785-0.801	138	90.8	93.0	0.81	92.5	174	86.8	94.9	0.80	93.0

Phase 2: MVPA cut-point for non-dominant wrist placement developed using Equivalency analysis

MVPA cases	Control cases	MVPA cases (a.u.)	Control cases (a.u.)	Equivalency analysis Cut-point (m*g*)	Sn (%)	Sp (%)	CK (a.u.)	%Ag (%)
MPA,VPA	SB, LPA	12832	42663	189	85.1	95.4	0.81	93.1

Dominant wrist placement

Phase 1: MVPA cut-points for dominant wrist placement developed using ROC analysis

MVPA cases	Control cases	MVPA cases (a.u.)	Control cases (a.u.)	AUC (a.u.)	AUC 95% CI (a.u.)	Youden cut-point (m*g*)	Sn (%)	Sp (%)	CK (a.u.)	%Ag (%)	Distance cut-point (m*g*)	Sn (%)	Sp (%)	CK (a.u.)	%Ag (%)
MPA,VPA	SB, LPA	12832	42663	0.968	0.966-0.969	109	91.0	89.9	0.74	90.1	109	91.0	89.9	0.74	90.1
MPA,VPA	SB, LPA excluding standing watching TV	12832	36723	0.963	0.962-0.965	125	89.9	91.6	0.75	91	119	89.9	90.9	0.76	90.7
MPA	LPA	12832	5059	0.866	0.860-0.871	80	94.4	85.5	0.74	87.6	104	91.6	89.3	0.70	89.8
MPA	LPA excluding standing watching TV	6405	5059	0.754	0.745-0.763	182	83.3	95.00	0.78	92.3	166	84.8	94.3	0.78	92.1

Phase 2: MVPA cut-point for dominant wrist placement developed using Equivalency analysis

MVPA cases	Control cases	MVPA cases (a.u.)	Control cases (a.u.)	Equivalency analysis Cut-point (m*g*)	Sn (%)	Sp (%)	CK (a.u.)	%Ag (%)
MPA,VPA	SB, LPA	12832	42663	181	83.4	95.0	0.78	92.3

Hip placement															
Phase 1: MVPA cut-points for hip placement developed using ROC analysis															
MVPA hip															
MVPA cases	**Control cases**	**MVPA cases (a.u.)**	**Control cases (a.u.)**	**AUC (a.u.)**	**AUC 95% CI (a.u.)**	**Youden cut-point (m*g*)**	**Sn (%)**	**Sp (%)**	**CK (a.u.)**	**%Ag (%)**	**Distance cut-point (m*g*)**	**Sn (%)**	**Sp (%)**	**CK (a.u.)**	**%Ag (%)**
MPA,VPA	SB, LPA	12832	42663	0.969	0.968-0.971	49	93.1	91.3	0.79	91.8	51	92.7	91.6	0.78	91.9
MPA,VPA	SB, LPA excluding standing watching TV	12832	36723	0.966	0.965-0.968	51	92.8	91.6	0.80	91.9	60	91.5	92.8	0.79	92.5
MPA	LPA	12832	5059	0.848	0.842-0.854	63	91.0	93.1	0.80	92.6	63	91.0	93.1	0.80	92.6
MPA	LPA excluding standing watching TV	6405	5059	0.733	0.724-0.742	87	86.8	95.0	0.81	93.2	88	86.7	95.1	0.81	93.2
Phase 2: MVPA cut-point for hip placement developed using Equivalency analysis															
MVPA cases	**Control cases**	**MVPA cases (a.u.)**	**Control cases (a.u.)**			**Equivalency analysis Cut-point (m*g*)**	**Sn (%)**	**Sp (%)**	**CK (a.u.)**	**%Ag (%)**					
MPA,VPA	SB, LPA	12832	42663			95	85.2	95.5	0.81	93.1					

MVPA cases: Number of observations of MVPA where each observation corresponds to 1 second

Control cases: Number if observations not including MVPA where each observation corresponds to 1 second

a.u.: arbitrary units

AUC: Area under the curve

AUC 95% CI: AUC 95% confidence interval

Sn: Sensitivity

Sp: Specificity

CK: Cohen's Kappa

%Ag: Percentage of agreement

Supplementary Table 5. Vigorous physical activity (VPA) cut-points and related variables

Non-dominant wrist placement

Phase 1: VPA cut-points for non-dominant wrist placement developed using ROC analysis

VPA cases	Control cases	VPA cases (a.u.)	Control cases (a.u.)	AUC (a.u.)	AUC 95% CI (a.u.)	Youden cut-point (m*g*)	Sn (%)	Sp (%)	CK (a.u.)	%Ag (%)	Distance cut-point (m*g*)	Sn (%)	Sp (%)	CK (a.u.)	%Ag (%)
VPA	SB, LPA, MPA	7773	47722	0.969	0.968-0.971	229	94.8	90.5	0.70	91.1	251	93.9	91.3	0.71	91.7
VPA	SB, LPA excluding standing watching TV, MPA	7773	41782	0.965	0.964-0.967	240	94.3	91.0	0.71	91.4	274	92.8	92	0.72	92.1
VPA	MPA	7773	5059	0.797	0.789-0.805	487	79.9	95.6	0.73	93.4	533	76.3	96.1	0.72	93.3

Phase 2: VPA cut-point for non-dominant wrist placement developed using Equivalency analysis

VPA cases	Control cases	VPA cases (a.u.)	Control cases (a.u.)	Equivalency analysis Cut-point (m*g*)	Sn (%)	Sp (%)	CK (a.u.)	%Ag (%)
VPA	SB, LPA, MPA	7773	47722	536	76	96.1	0.72	93.3

Dominant wrist placement

Phase 1: VPA cut-points for dominant wrist placement developed using ROC analysis

VPA cases	Control cases	VPA cases (a.u.)	Control cases (a.u.)	AUC (a.u.)	AUC 95% CI (a.u.)	Youden cut-point (m*g*)	Sn (%)	Sp (%)	CK (a.u.)	%Ag (%)	Distance cut-point (m*g*)	Sn (%)	Sp (%)	CK (a.u.)	%Ag (%)
VPA	SB, LPA, MPA	7773	47722	0.969	0.967-0.97	227	94.6	90.2	0.68	90.8	241	94.1	90.6	0.69	91.1
VPA	SB, LPA excluding standing watching TV, MPA	7773	41782	0.964	0.963-0.966	227	94.6	90.2	0.68	90.8	261	93.2	91.3	0.70	91.5
VPA	MPA	7773	5059	0.807	0.799-0.815	460	82.5	94.8	0.72	93.2	542	76.4	95.7	0.71	93.2

Phase 2: VPA cut-point for dominant wrist placement developed using Equivalency analysis

VPA cases	Control cases	VPA cases (a.u.)	Control cases (a.u.)	Equivalency analysis Cut-point (m*g*)	Sn (%)	Sp (%)	CK (a.u.)	%Ag (%)
VPA	SB, LPA, MPA.	7773	47722	534	76.9	95.7	0.71	93.2

Hip placement															
Phase 1: VPA cut-points for hip placement developed using ROC analysis															
VPA cases	**Control cases**	**VPA cases (a.u.)**	**Control cases (a.u.)**	**AUC (a.u.)**	**AUC 95% CI (a.u.)**	**Youden cut-point (m*g*)**	**Sn (%)**	**Sp (%)**	**CK (a.u.)**	**%Ag (%)**	**Distance cut-point (m*g*)**	**Sn (%)**	**Sp (%)**	**CK (a.u.)**	**%Ag (%)**
VPA	SB, LPA, MPA	7773	47722	0.980	0.979-0.981	147	95.1	92.2	0.73	92.6	166	94.1	93.2	0.75	93.3
VPA	SB, LPA excluding standing watching TV, MPA	7773	41782	0.977	0.976-0.978	166	94.1	93.2	0.75	93.3	166	94.1	93.2	0.75	93.3
VPA	MPA	7773	5059	0.872	0.866-0.879	294	86.4	96.3	0.79	95	305	85.5	96.5	0.79	95
Phase 2: VPA cut-point for hip placement developed using Equivalency analysis															
VPA cases	**Control cases**	**VPA cases (a.u.)**	**Control cases (a.u.)**			**Equivalency analysis Cut-point (m*g*)**	**Sn (%)**	**Sp (%)**	**CK (a.u.)**	**%Ag (%)**					
VPA	SB, LPA, MPA	7773	47722			325	83.5	96.7	0.78	94.9					

VPA cases: Number of observations of VPA where each observation corresponds to 1 second

Control cases: Number if observations not including VPA where each observation corresponds to 1 second

a.u.: arbitrary units

AUC: Area under the curve

AUC 95% CI: AUC 95% confidence interval

Sn: Sensitivity

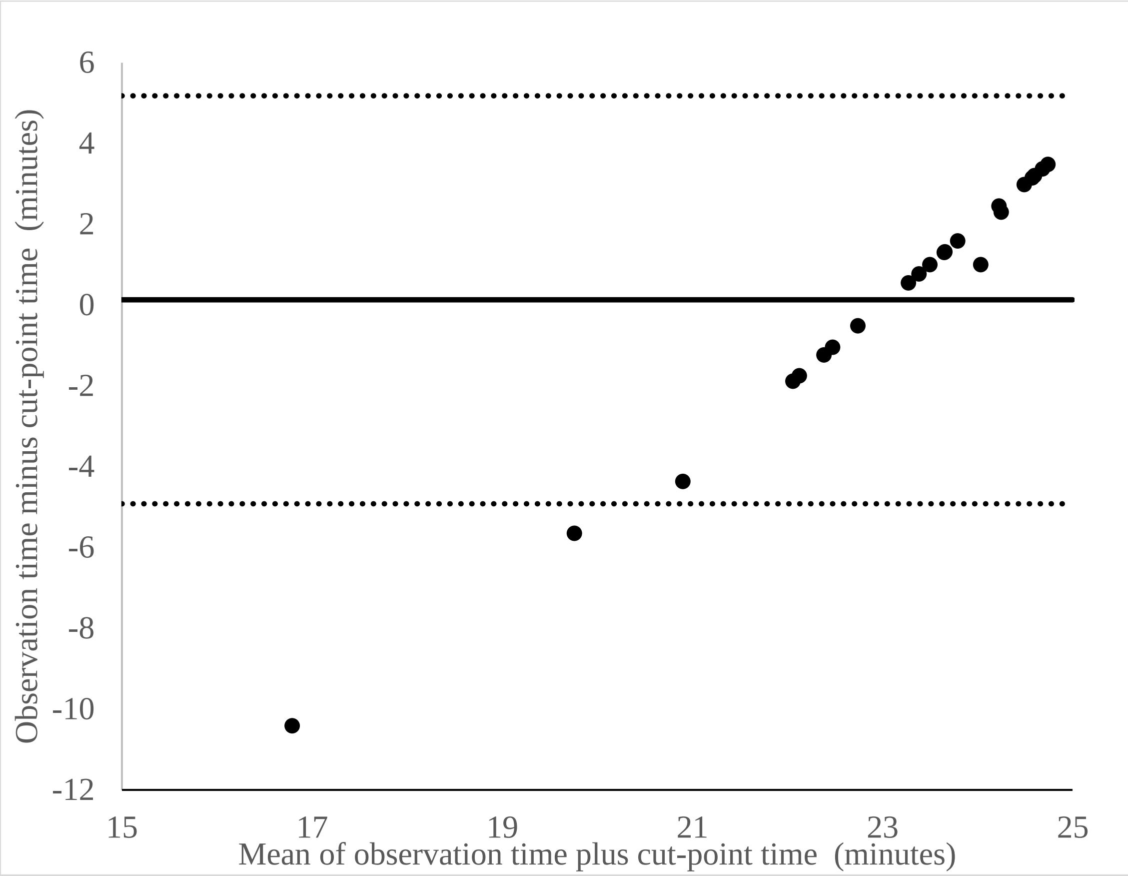
Sp: Specificity

CK: Cohen's Kappa

%Ag: Percentage of agreement

Supplementary material 4. Phase 2 data analysis - Bland Altman plots in study 1

Supplementary Figure 1. Non-dominant wrist - Sedentary behaviours



Phase 2 cut-point: <36

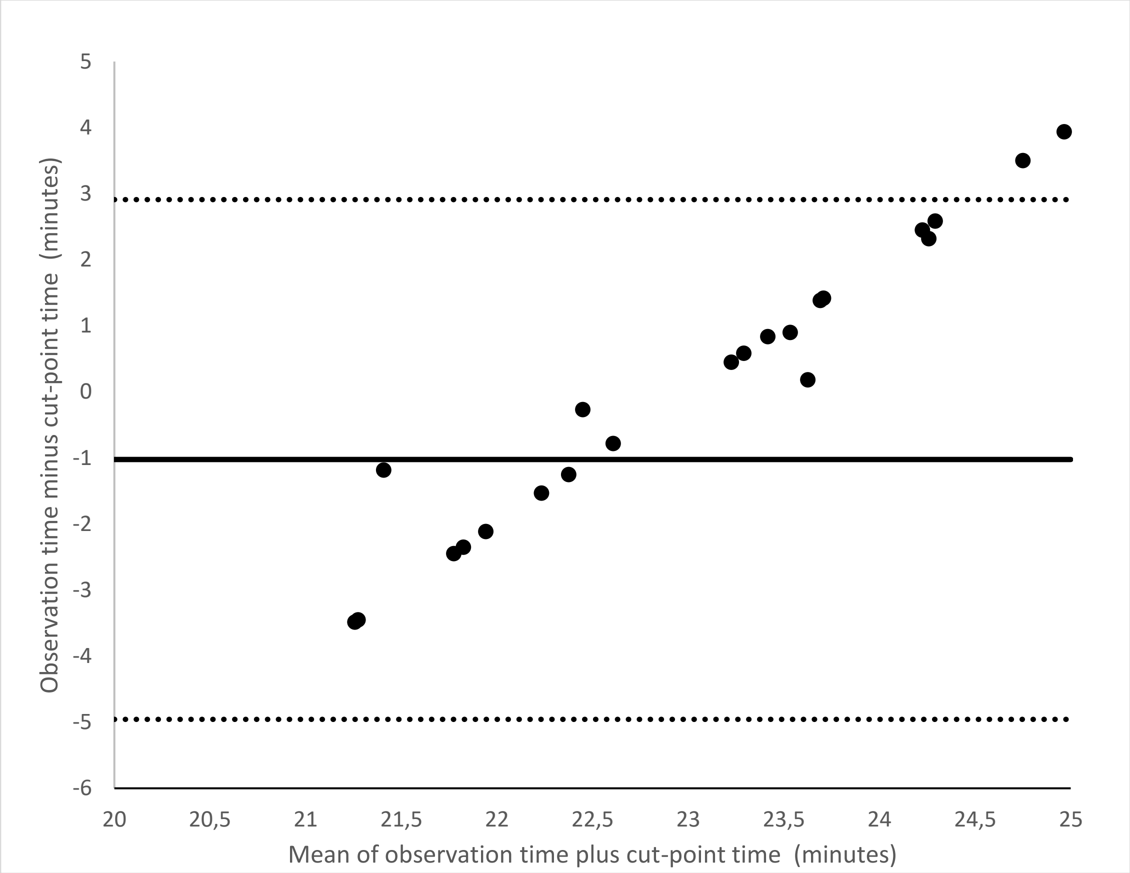
Mean difference: 0.132

Upper limit of agreement: 5.181

Lower limit of agreement: -4.917

A linear relation between bias and average of the differences was observed in Bland Altman plots of Sedentary behaviours as children engaged in approximatively the same amount of Sedentary behaviours (23min). This is because they engaged in little or no Sedentary behaviours during playtime. Therefore an increase in the Cut-points derived sedentary behavior would result in a linear increase in observation time minus cut-point time (y axis).

Supplementary Figure 2. Dominant wrist - Sedentary behaviours



Phase 2 cut-point: <39

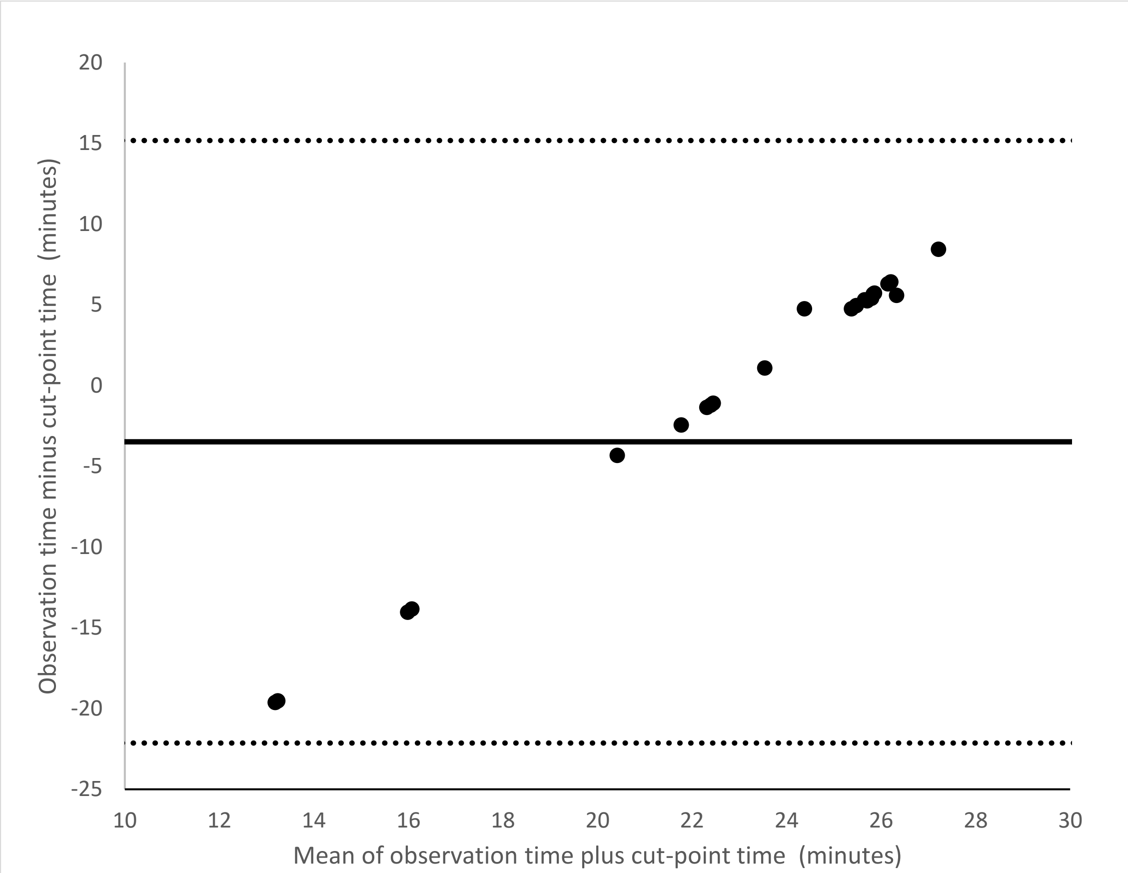
Mean difference: -1.023

Upper limit of agreement: 2.910

Lower limit of agreement: -4.957

A linear relation between bias and average of the differences was observed in Bland Altman plots of Sedentary behaviours as children engaged in approximatively the same amount of Sedentary behaviours (23min). This is because they engaged in little or no Sedentary behaviours during playtime. Therefore an increase in the Cut-points derived sedentary behavior would result in a linear increase in observation time minus cut-point time (y axis).

Supplementary Figure 3. Hip - Sedentary behaviours



Phase 2 cut-point: <20

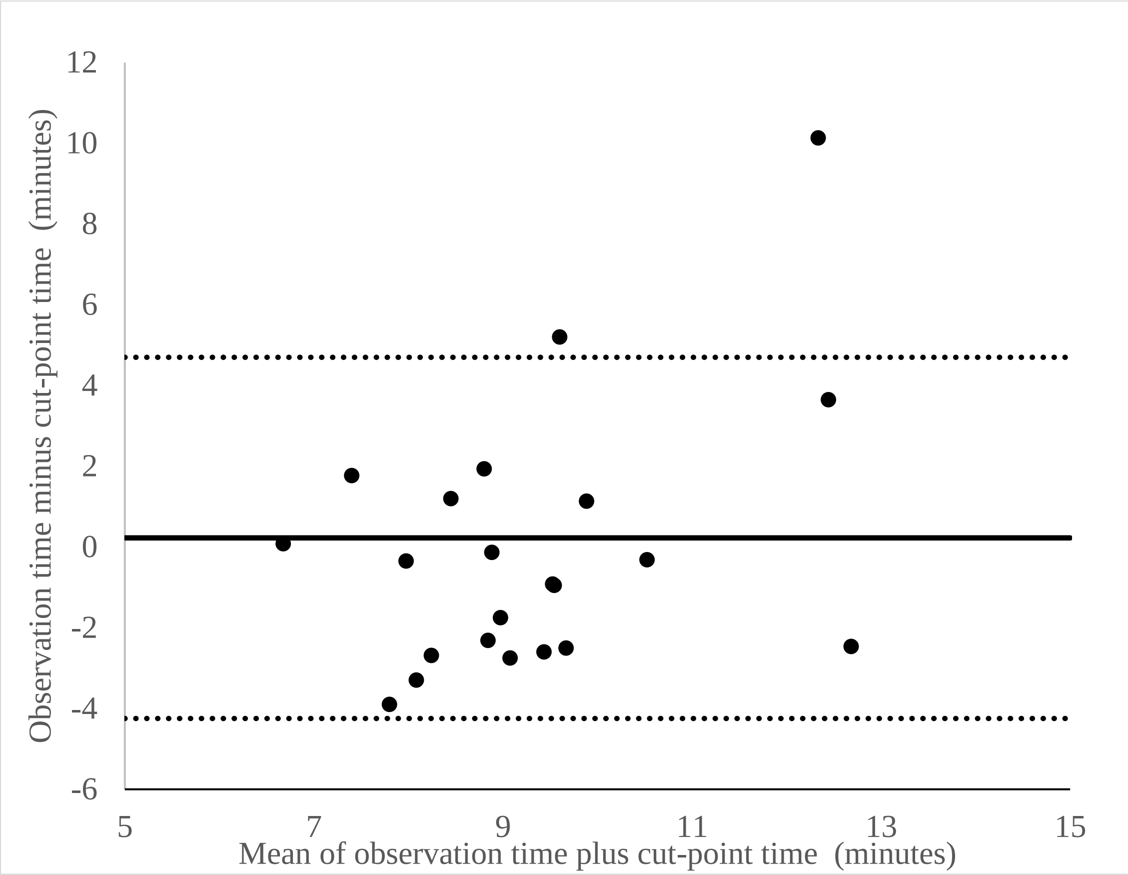
Mean difference: -1.023

Upper limit of agreement: 15.170

Lower limit of agreement: -22.137

A linear relation between bias and average of the differences was observed in Bland Altman plots of Sedentary behaviours as children engaged in approximatively the same amount of Sedentary behaviours (23min). This is because they engaged in little or no Sedentary behaviours during playtime. Therefore an increase in the Cut-points derived sedentary behavior would result in a linear increase in observation time minus cut-point time (y axis).

Supplementary Figure 4. Non-dominant wrist - Light physical activity



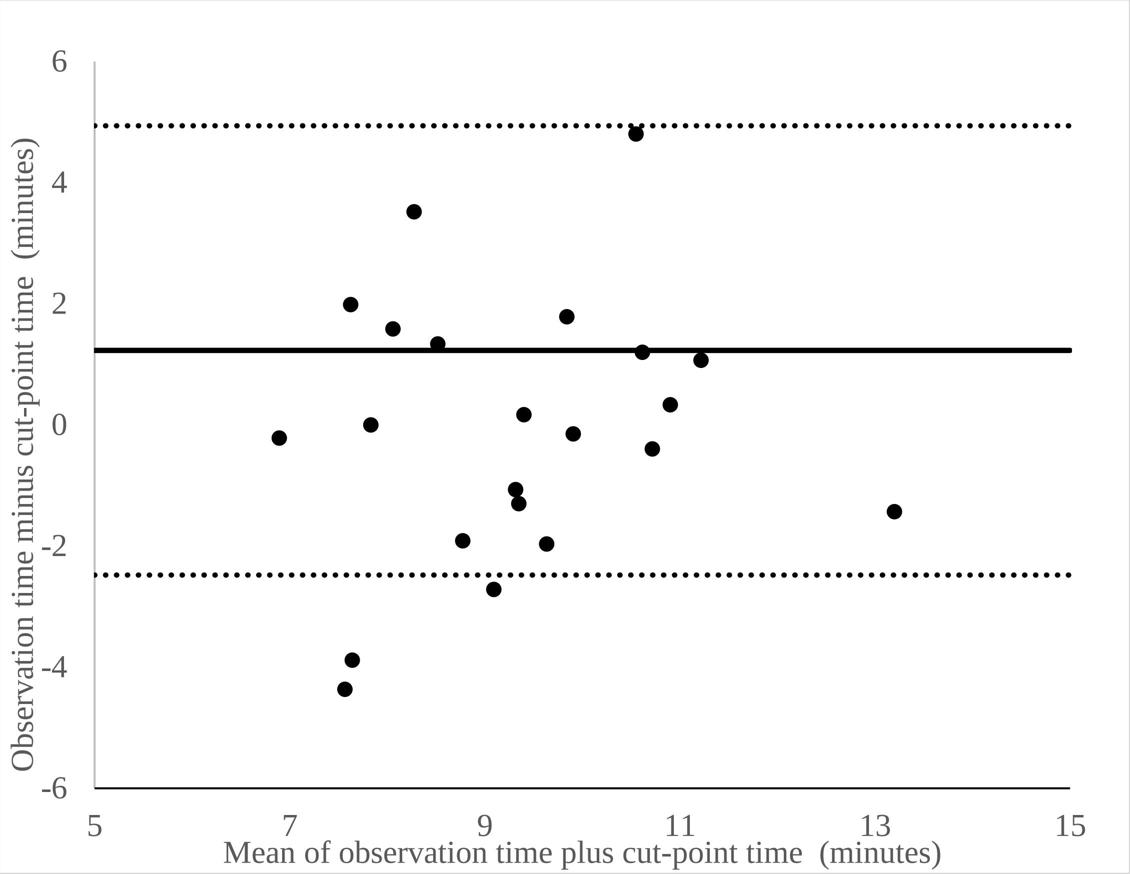
Phase 2 cut-point: ≥36&<189

Mean difference: 0.227

Upper limit of agreement: 4.610

Lower limit of agreement: -4.246

Supplementary Figure 5. Dominant wrist - Light physical activity



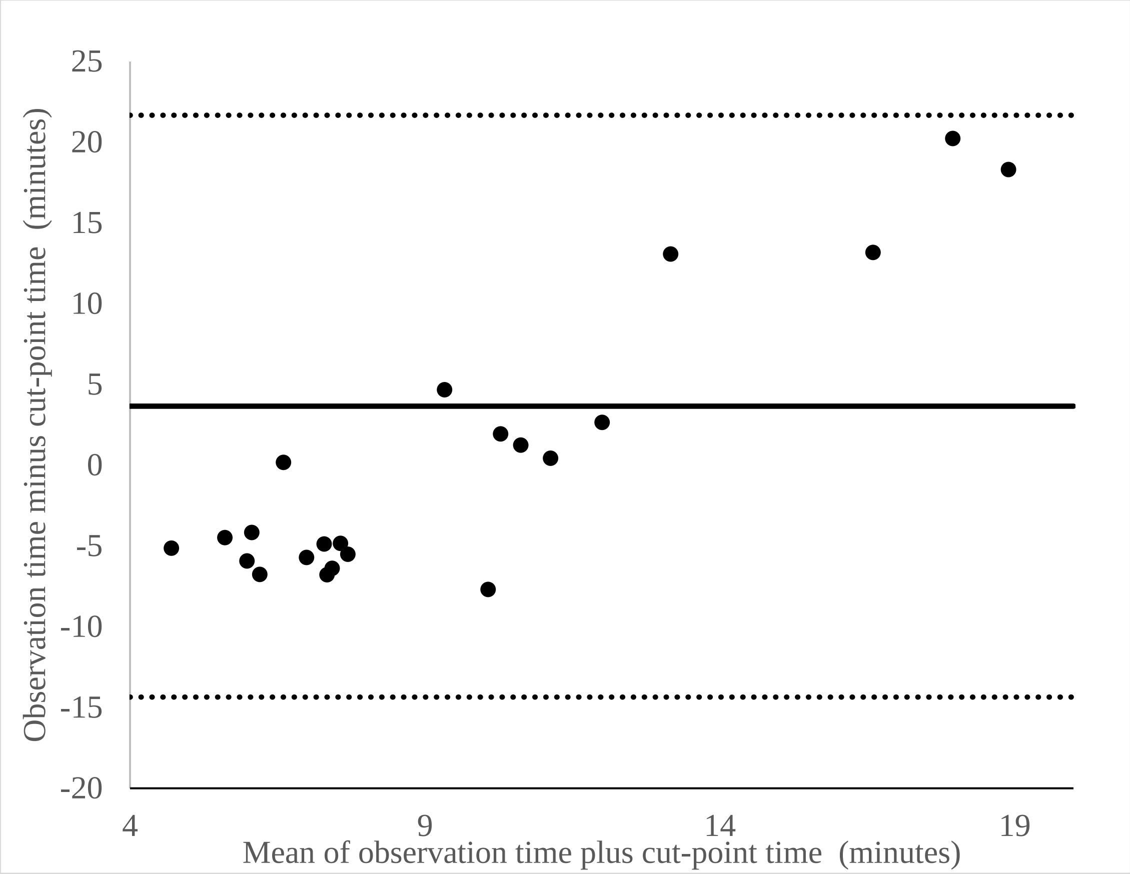
Phase 2 cut-point: ≥39&<181

Mean difference: 1.230

Upper limit of agreement: 4.939

Lower limit of agreement: -2.479

Supplementary Figure 6. Hip - Light physical activity



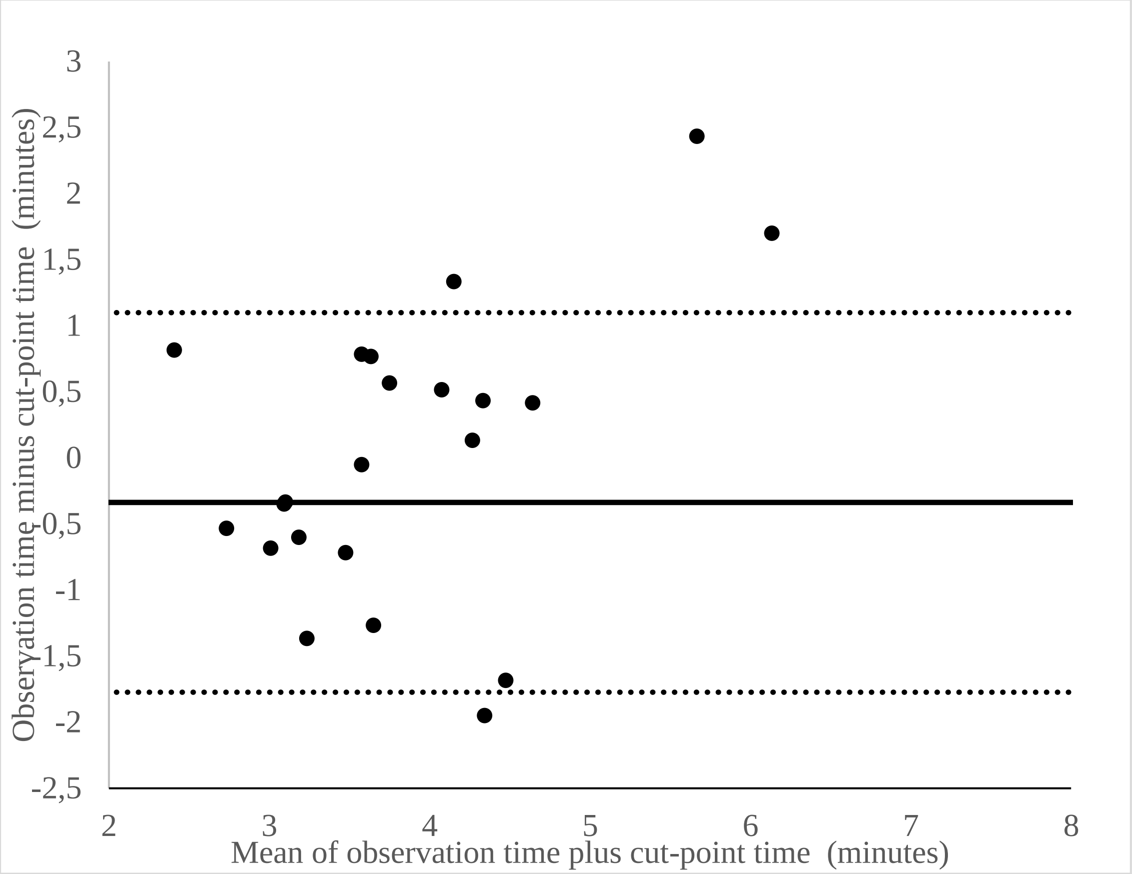
Phase 2 cut-point: ≥20<95

Mean difference: 3.660

Upper limit of agreement: 21.673

Lower limit of agreement: -14.353

Supplementary Figure 7. Non-dominant wrist - Moderate physical activity



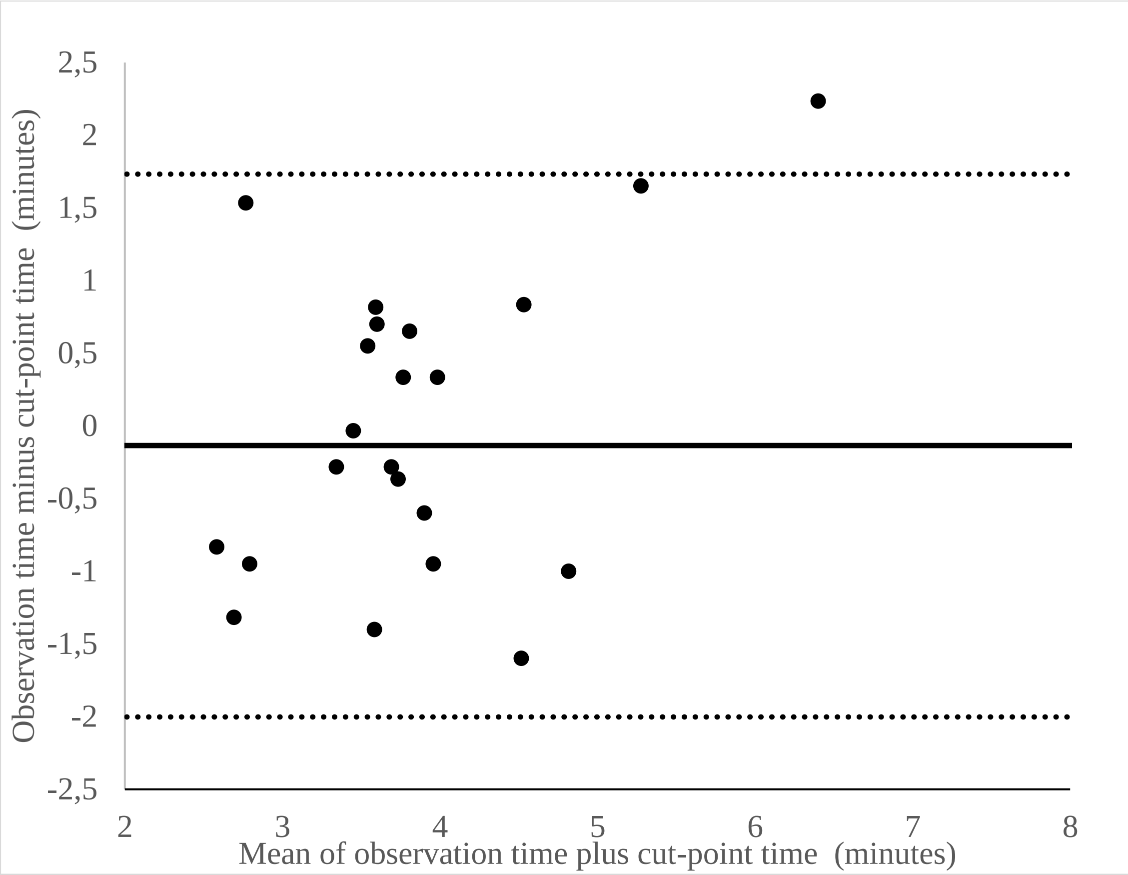
Phase 2 cut-point: ≥189&<536

Mean difference: -0.337

Upper limit of agreement: 1.010

Lower limit of agreement: -1.773

Supplementary Figure 8. Dominant wrist - Moderate physical activity



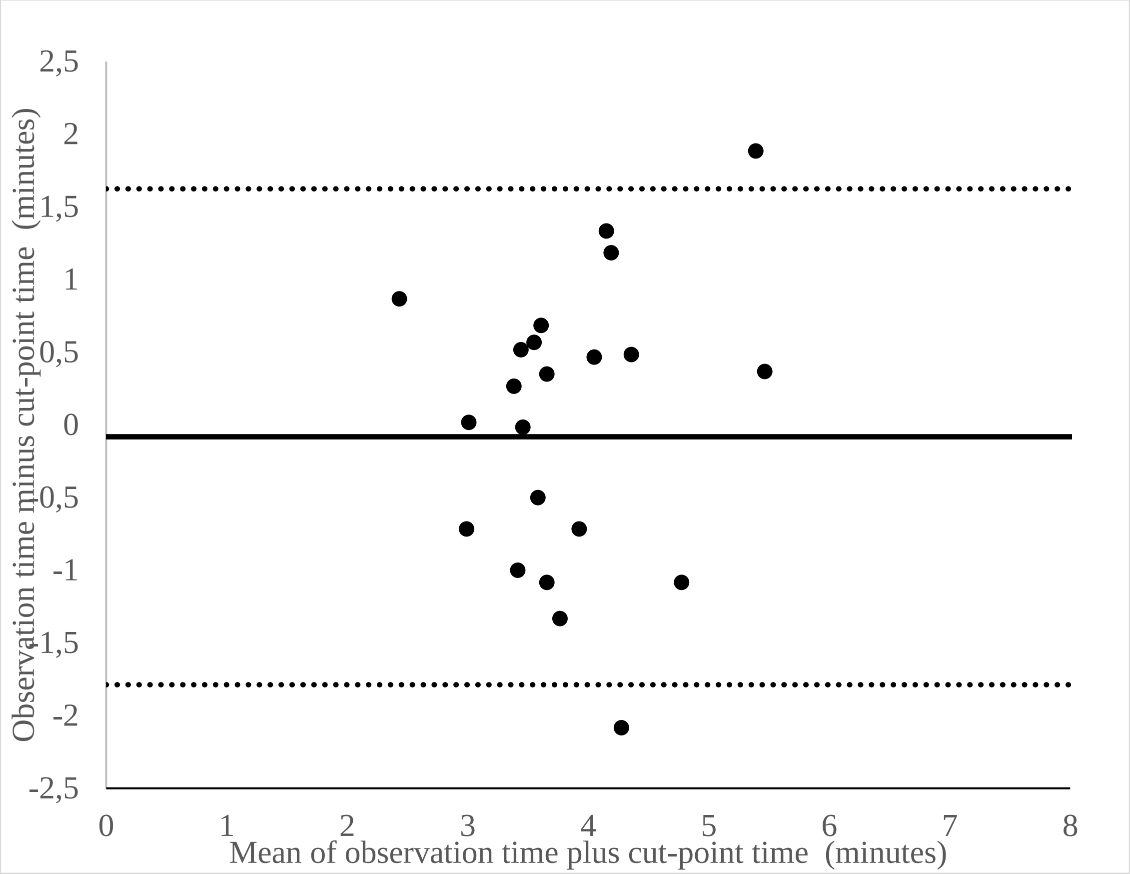
Phase 2 cut-point: ≥181<534

Mean difference: -0.135

Upper limit of agreement: 1.732

Lower limit of agreement: -2.002

Supplementary Figure 9. Hip - Moderate physical activity



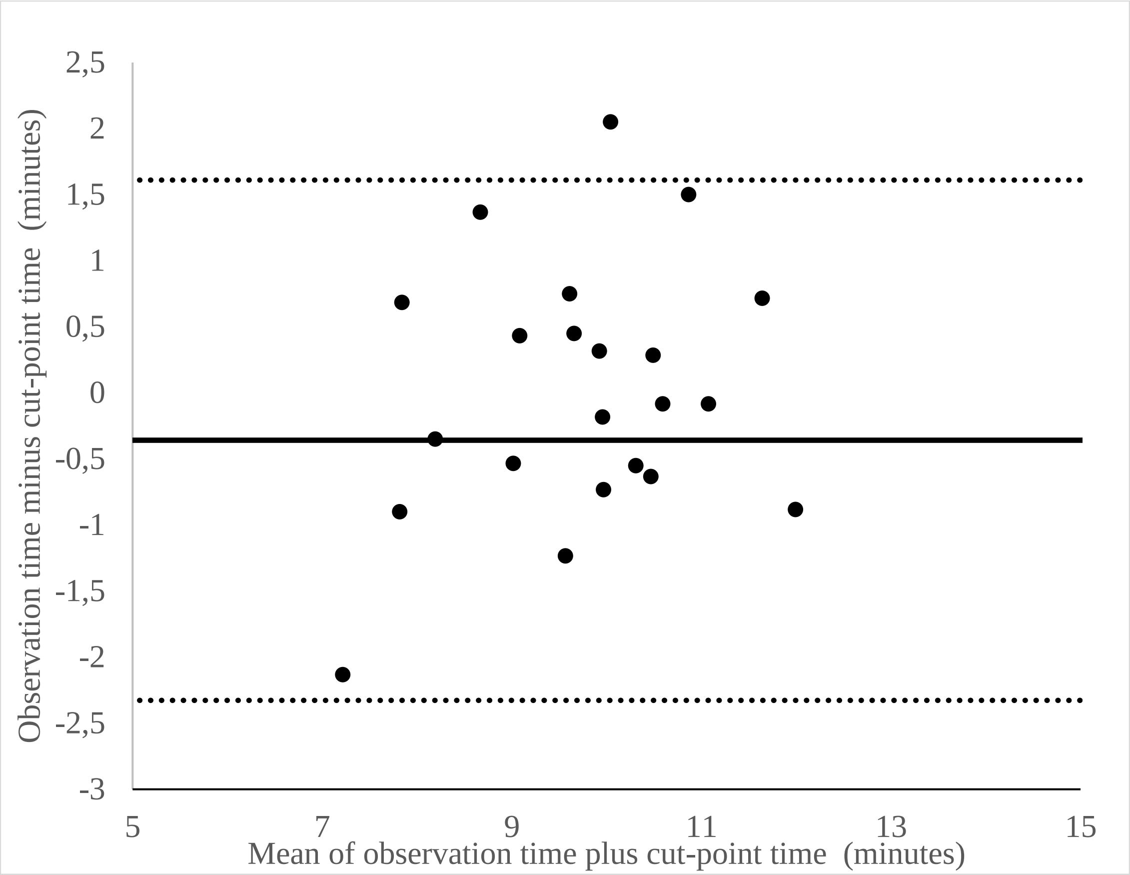
Phase 2 cut-point: ≥95&<325

Mean difference: -0.0817

Upper limit of agreement: 1.624

Lower limit of agreement: -1.787

Supplementary Figure 10. Non-dominant wrist - Moderate to vigorous physical activity



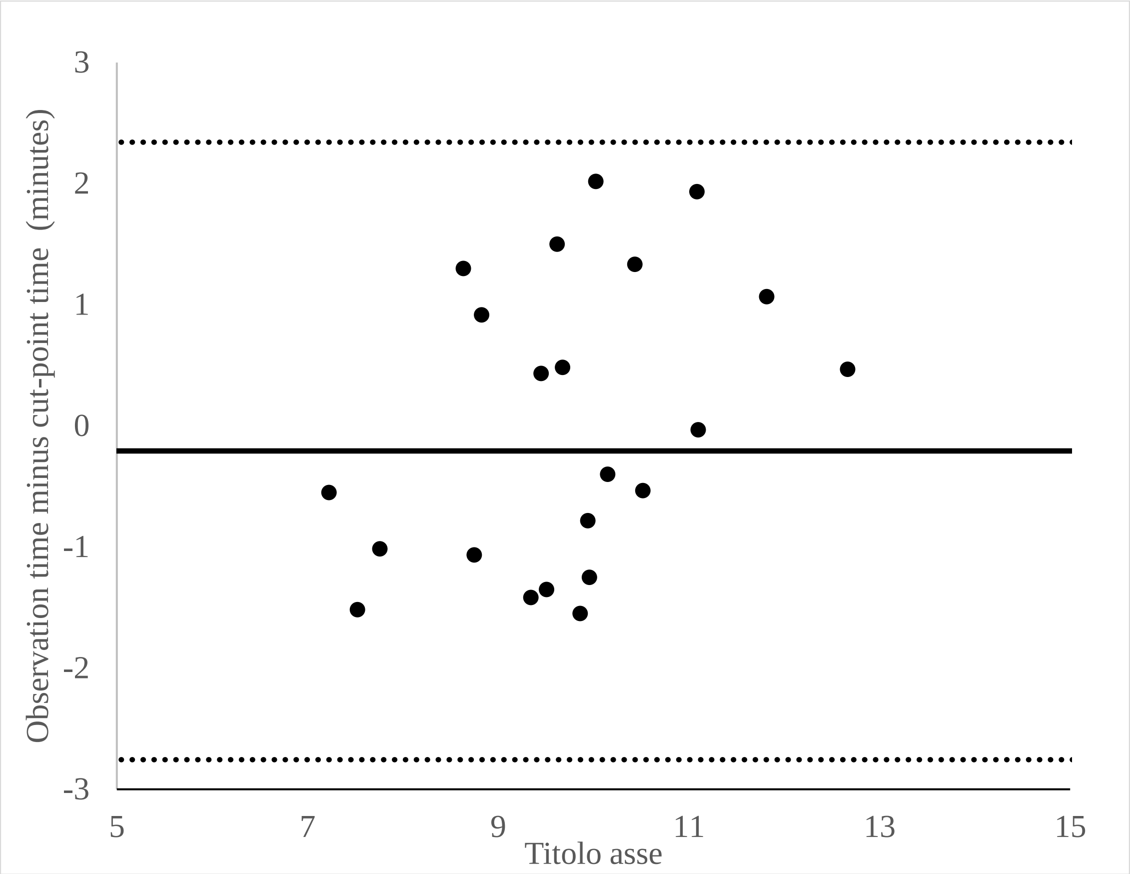
Phase 2 cut-point: ≥189

Mean difference: -0.358

Upper limit of agreement: 1.610

Lower limit of agreement: -2.327

Supplementary Figure 11. Non-dominant wrist - Moderate to vigorous physical activity



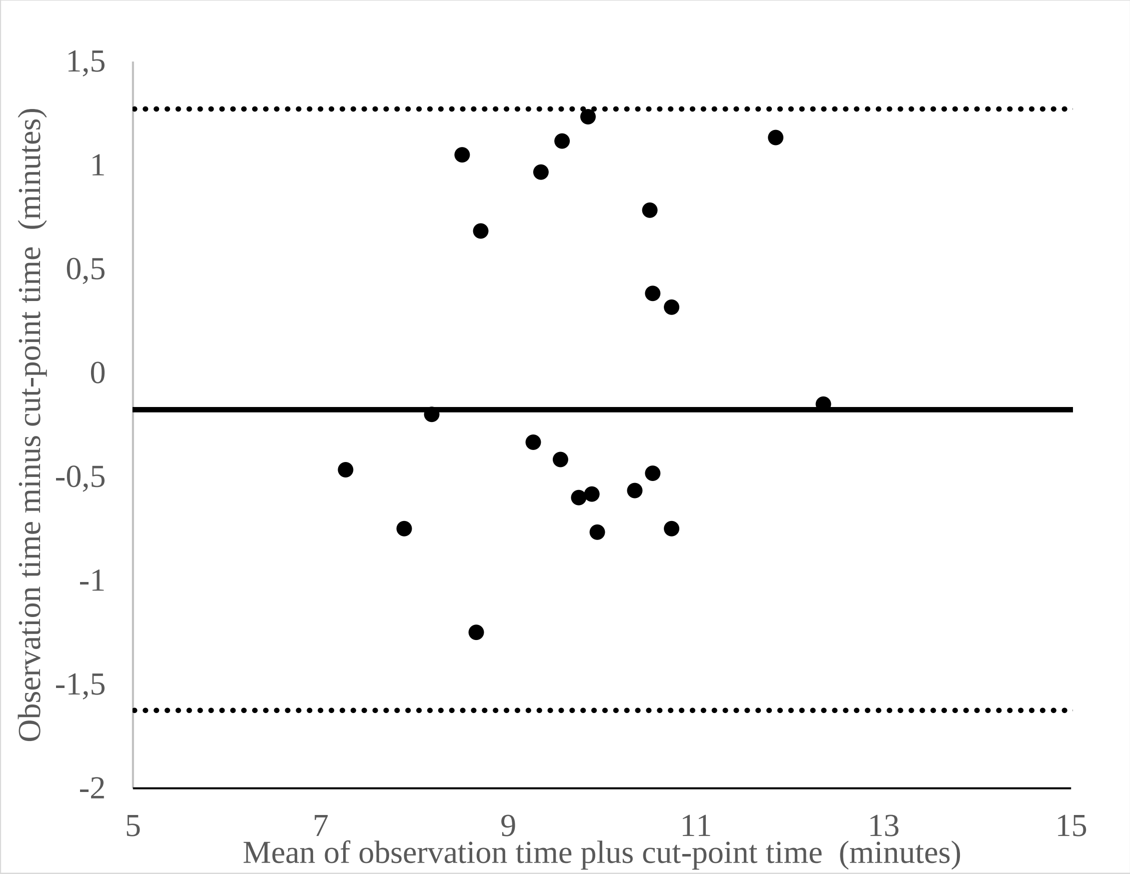
Phase 2 cut-point: ≥181

Mean difference: -0.207

Upper limit of agreement: 2.342

Lower limit of agreement: -2.756

Supplementary Figure 12. Hip - Moderate to vigorous physical activity



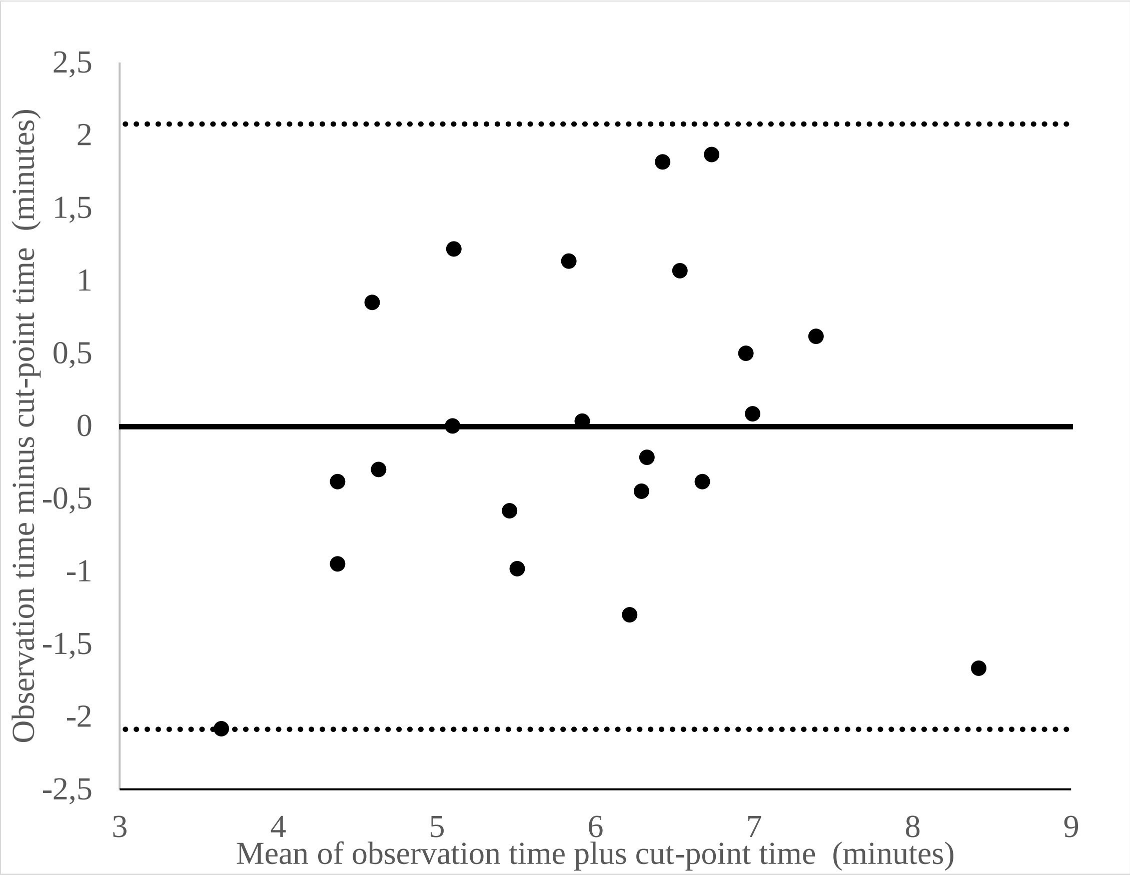
Phase 2 cut-point: ≥95

Mean difference: -0.177

Upper limit of agreement: 1.271

Lower limit of agreement: -1.625

Supplementary Figure 13. Non-dominant wrist - Vigorous physical activity



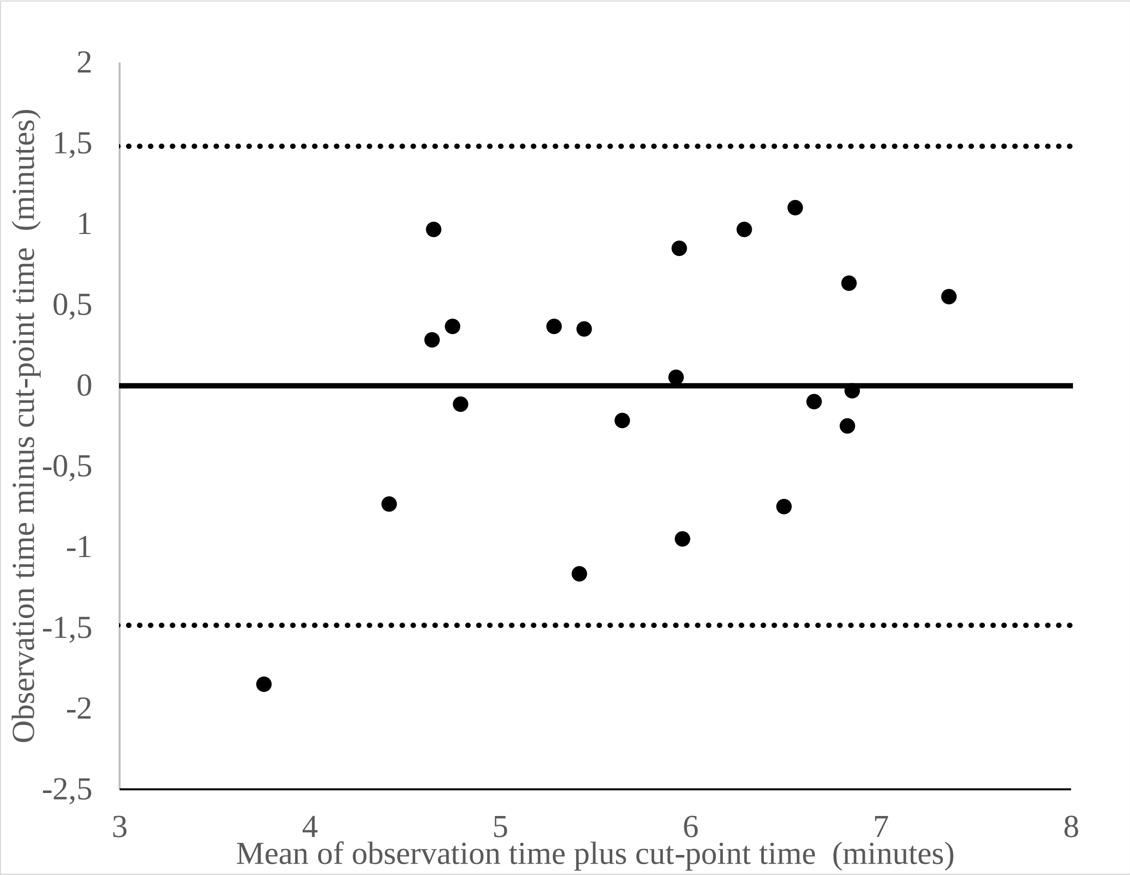
Phase 2 cut-point: ≥536

Mean difference: -0.005

Upper limit of agreement: 2.077

Lower limit of agreement: -2.087

Supplementary Figure 14. Dominant wrist - Vigorous physical activity



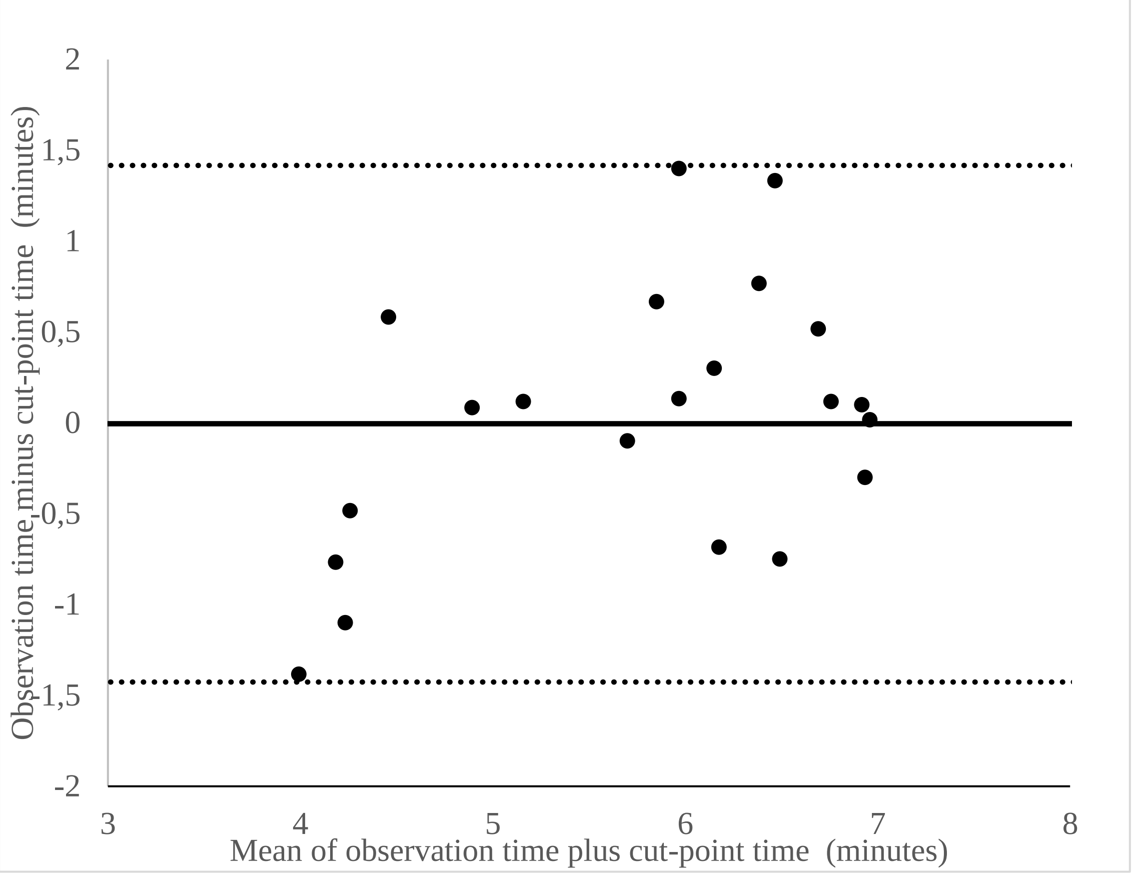
Phase 2 cut-point: ≥534

Mean difference: -0.002

Upper limit of agreement: 1.481

Lower limit of agreement: -1.485

Supplementary Figure 15. Hip - Vigorous physical activity



Phase 2 cut-point: ≥325

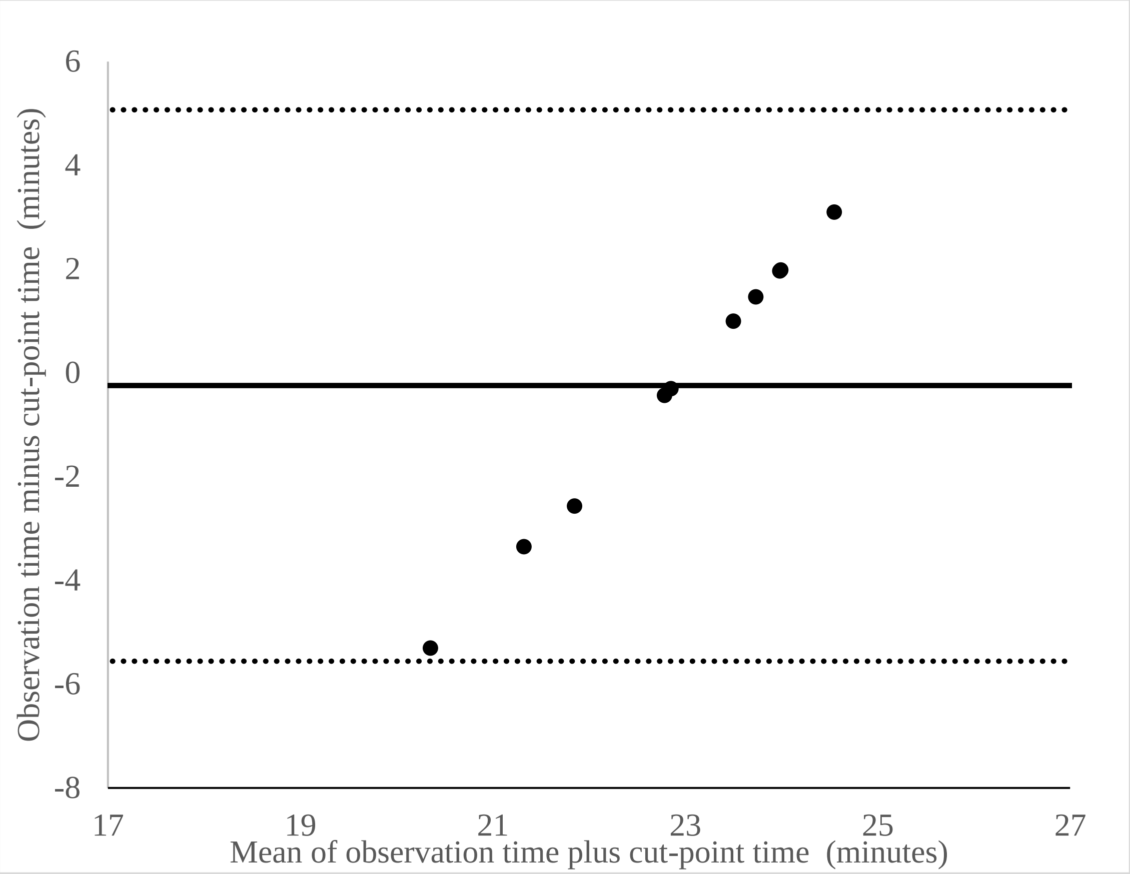
Mean difference: -0.005

Upper limit of agreement: 1.417

Lower limit of agreement: -1.426

Phase 3 data analysis - Bland Altman Plots

Supplementary Figure 16. Non-dominant wrist - Sedantary behaviours



Phase 2 cut-point: <36

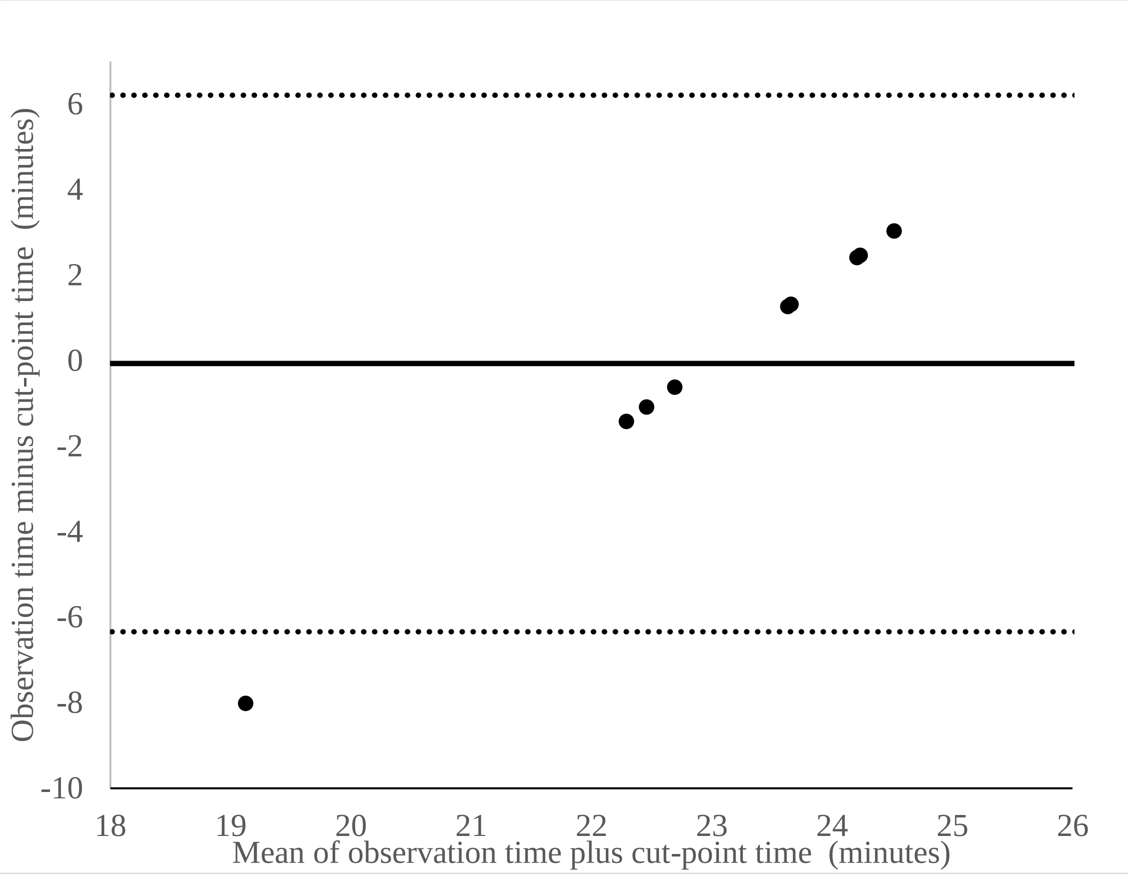
Mean difference: -0.243

Upper limit of agreement: 5.070

Lower limit of agreement: -5.557

A linear relation between bias and average of the differences was observed in Bland Altman plots of Sedentary behaviours as children engaged in approximatively the same amount of Sedentary behaviours (23min). This is because they engaged in little or no Sedentary behaviours during playtime. Therefore an increase in the Cut-points derived sedentary behavior would result in a linear increase in observation time minus cut-point time (y axis).

Supplementary Figure 17. Dominant wrist - Sedentary behaviours



Phase 2 cut-point: <39

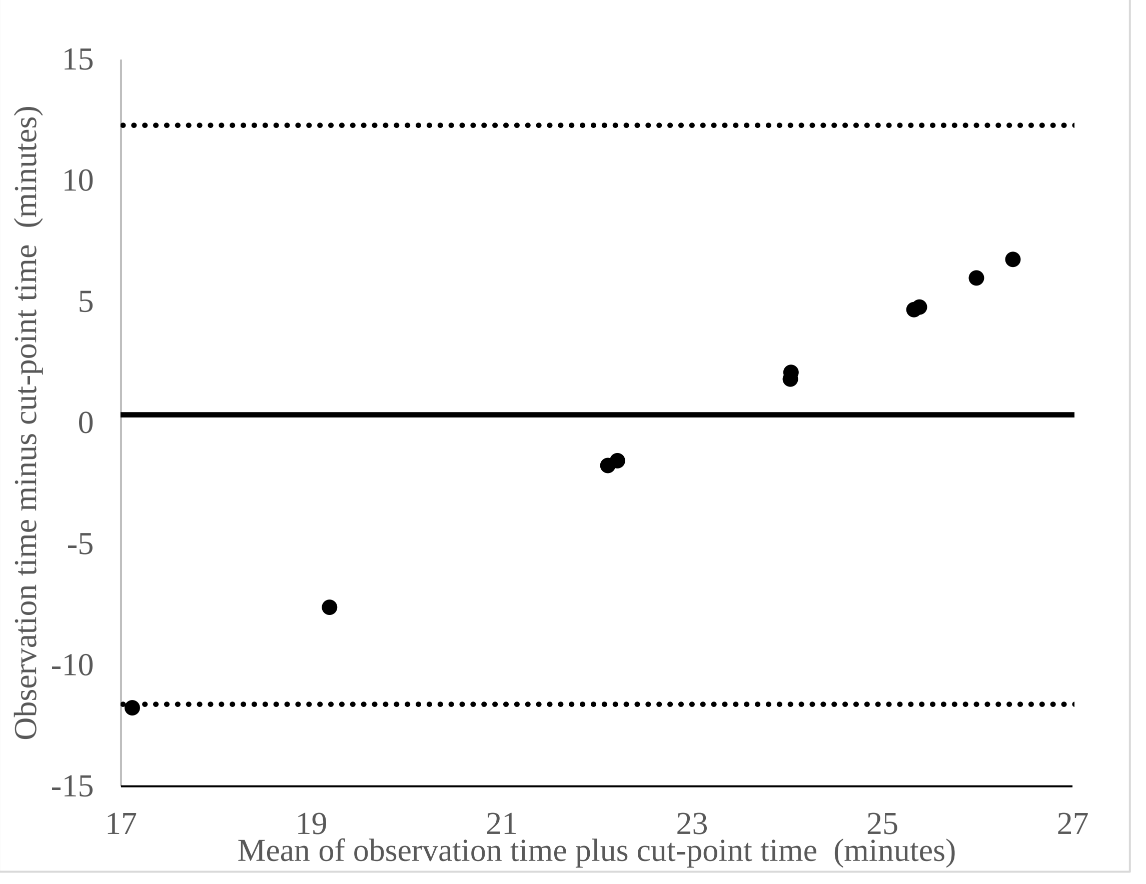
Mean difference: -0.063

Upper limit of agreement: 6.212

Lower limit of agreement: -6.338

A linear relation between bias and average of the differences was observed in Bland Altman plots of Sedentary behaviours as children engaged in approximatively the same amount of Sedentary behaviours (23min). This is because they engaged in little or no Sedentary behaviours during playtime. Therefore an increase in the Cut-points derived sedentary behavior would result in a linear increase in observation time minus cut-point time (y axis).

Supplementary Figure 18. Hip - Sedentary behaviours



Phase 2 cut-point: <20

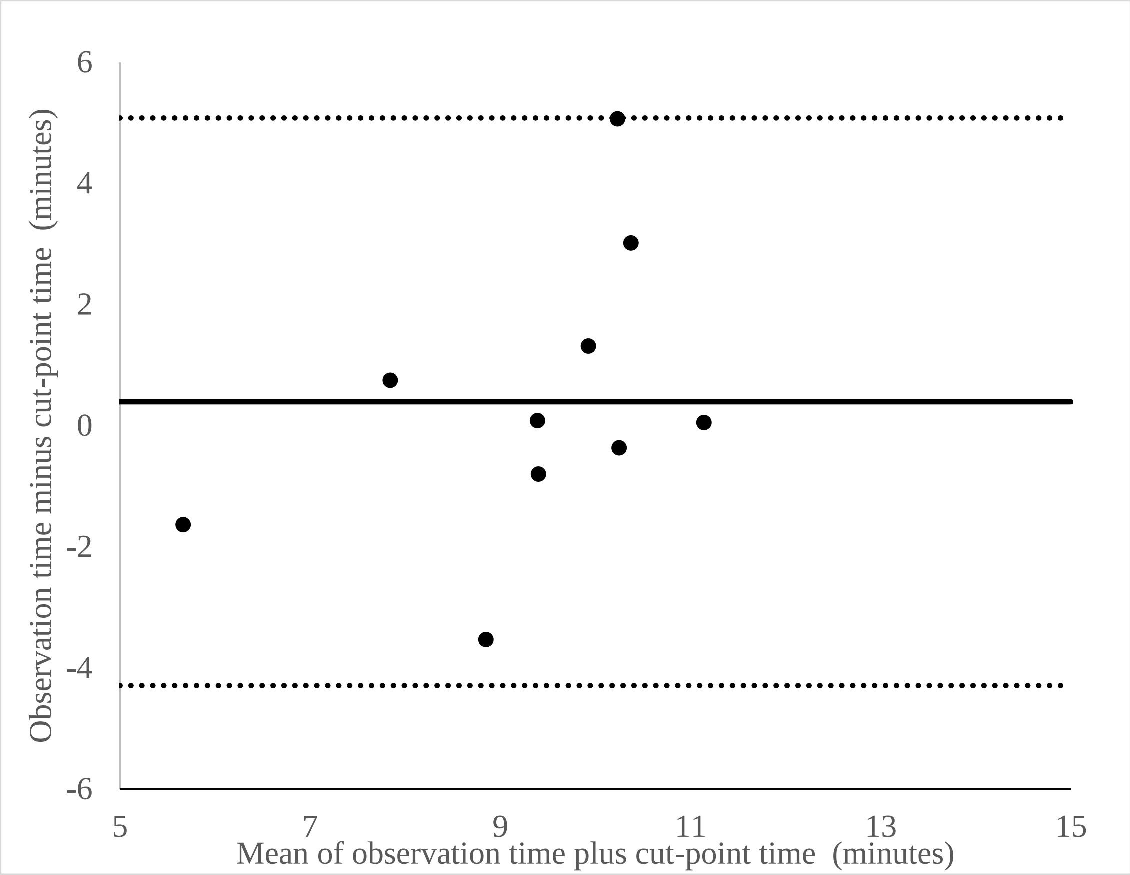
Mean difference: 0.335

Upper limit of agreement: 12.284

Lower limit of agreement: -11.614

A linear relation between bias and average of the differences was observed in Bland Altman plots of Sedentary behaviours as children engaged in approximatively the same amount of Sedentary behaviours (23min). This is because they engaged in little or no Sedentary behaviours during playtime. Therefore an increase in the Cut-points derived sedentary behavior would result in a linear increase in observation time minus cut-point time (y axis).

Supplementary Figure 19. Non-dominant wrist - Light physical activity



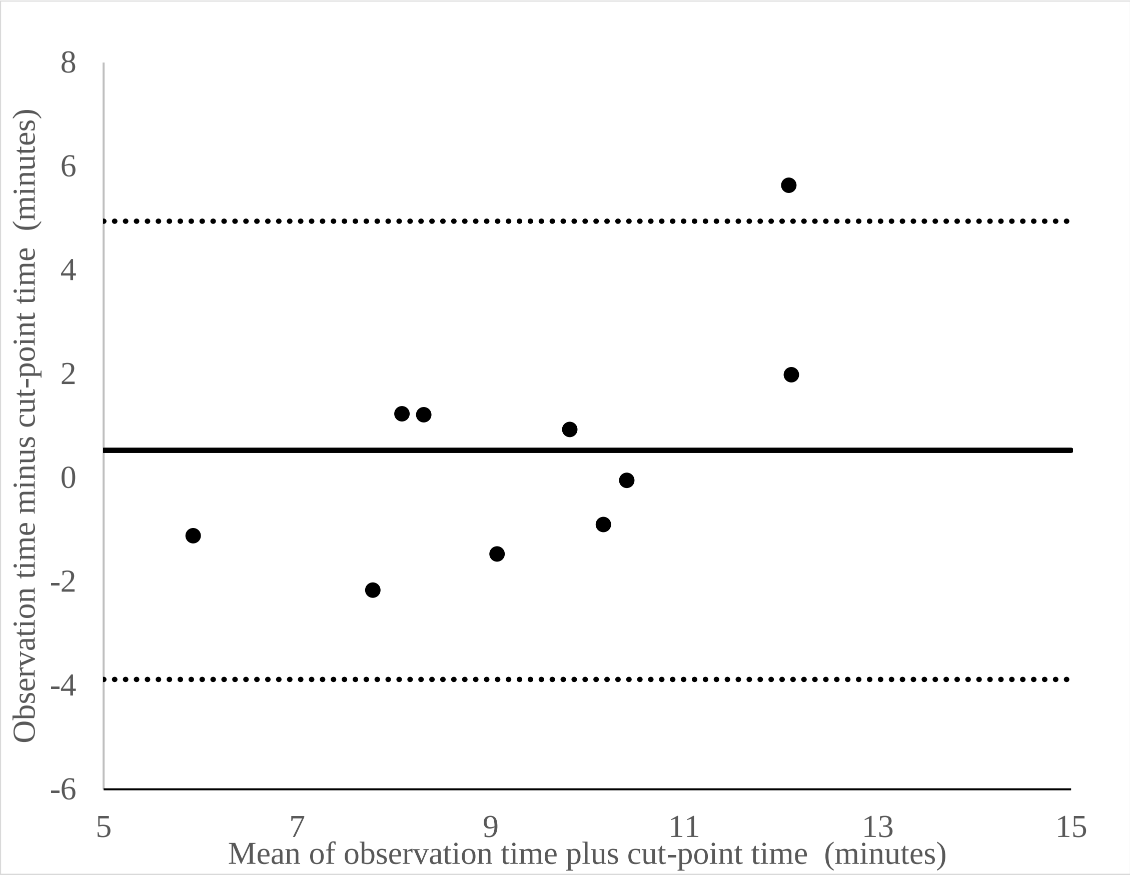
Phase 2 cut-point: ≥36&<189

Mean difference: 0.395

Upper limit of agreement: 5.081

Lower limit of agreement: -4.291

Supplementary Figure 20. Dominant wrist - Light physical activity



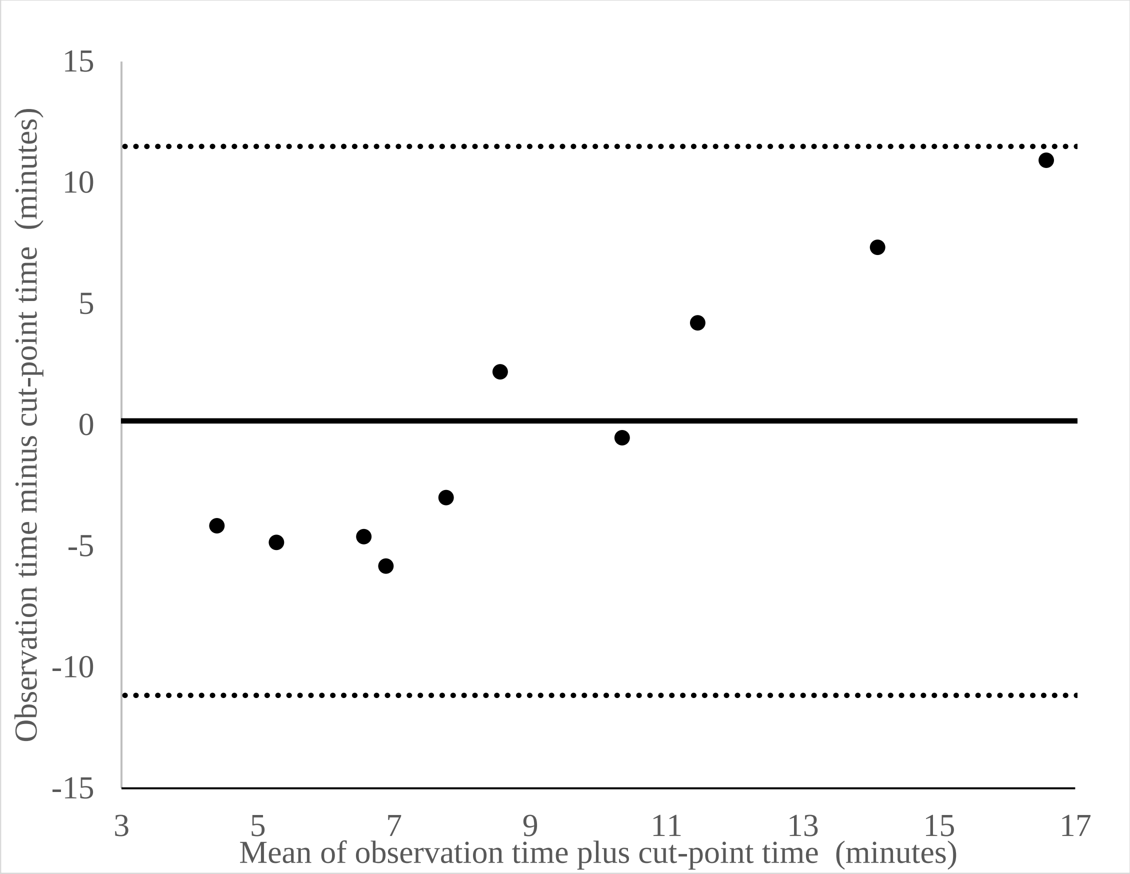
Phase 2 cut-point: ≥39&<181

Mean difference: 0.53

Upper limit of agreement: 4.944

Lower limit of agreement: -3.884

Supplementary Figure 21. Hip - Light Physical activity



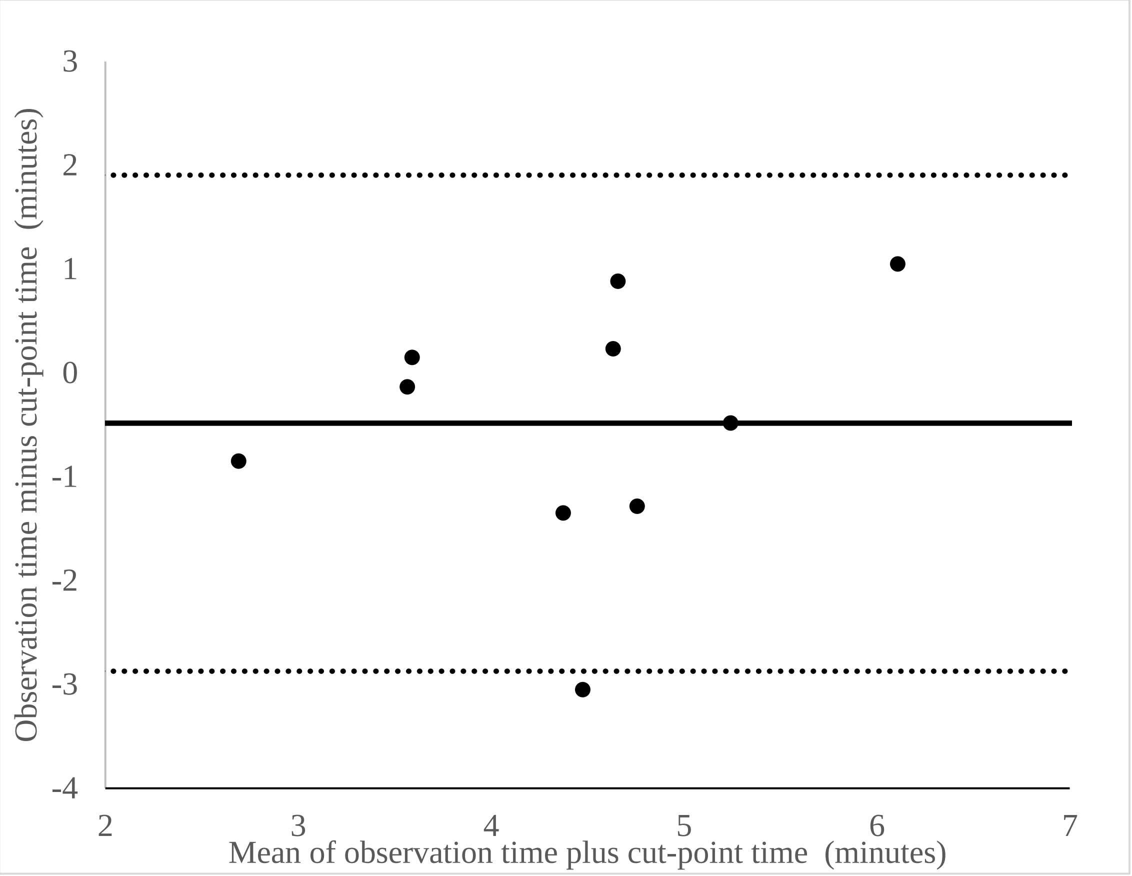
Phase 2 cut-point: ≥20&<95

Mean difference: 0.165

Upper limit of agreement: 11.495

Lower limit of agreement: -11.165

Supplementary Figure 22. Non-dominant wrist - Moderate Physical activity



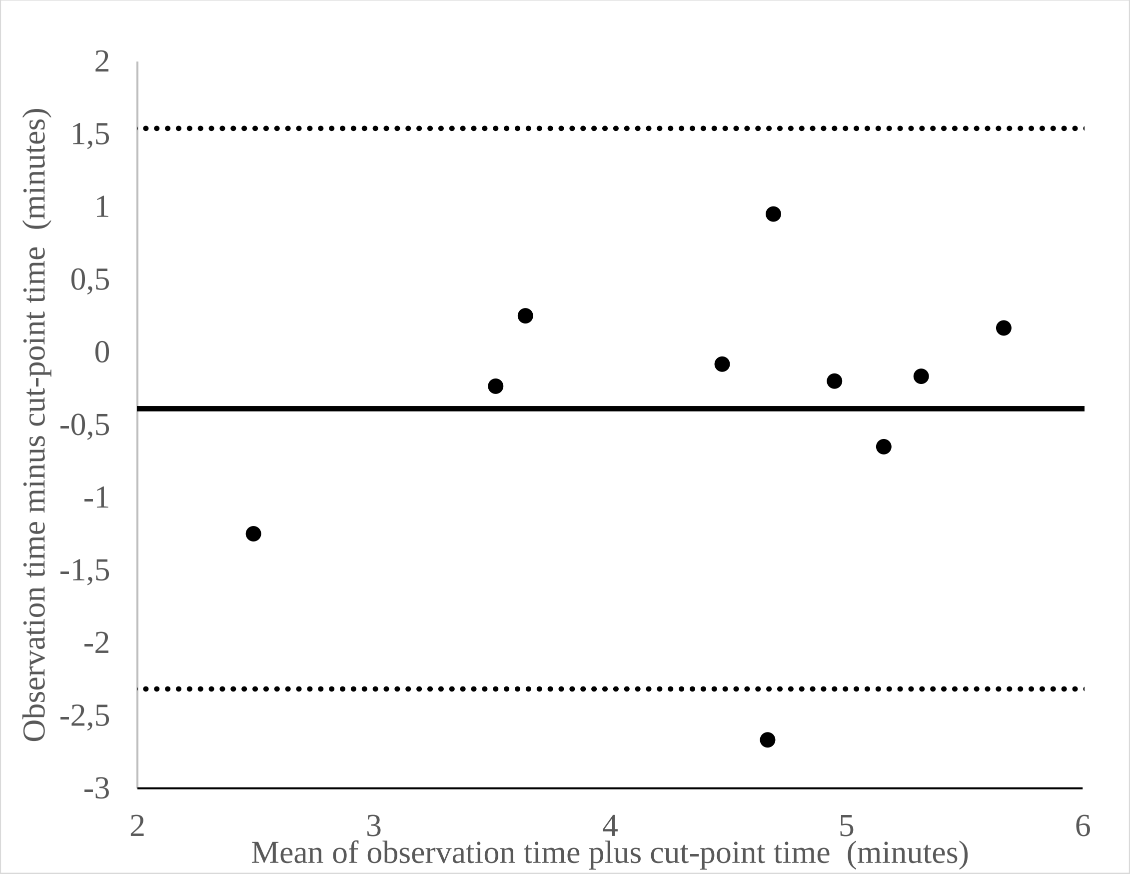
Phase 2 cut-point: ≥189<536

Mean difference: -0.483

Upper limit of agreement: 1.906

Lower limit of agreement: -2.872

Supplementary Figure 23. Dominant wrist - Moderate physical activity



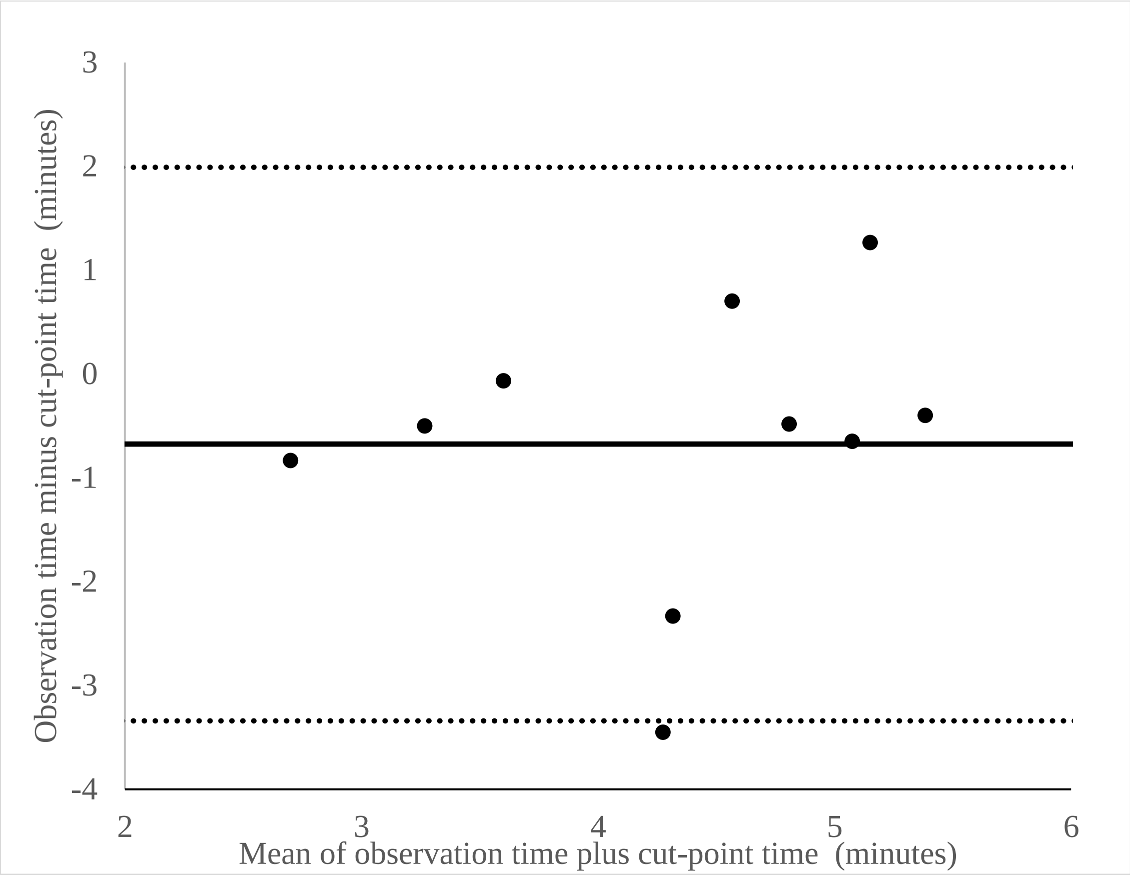
Phase 2 cut-point: ≥181&<534

Mean difference: -0.388

Upper limit of agreement: 1.540

Lower limit of agreement: -2.317

Supplementary Figure 24. Hip - Moderate physical activity



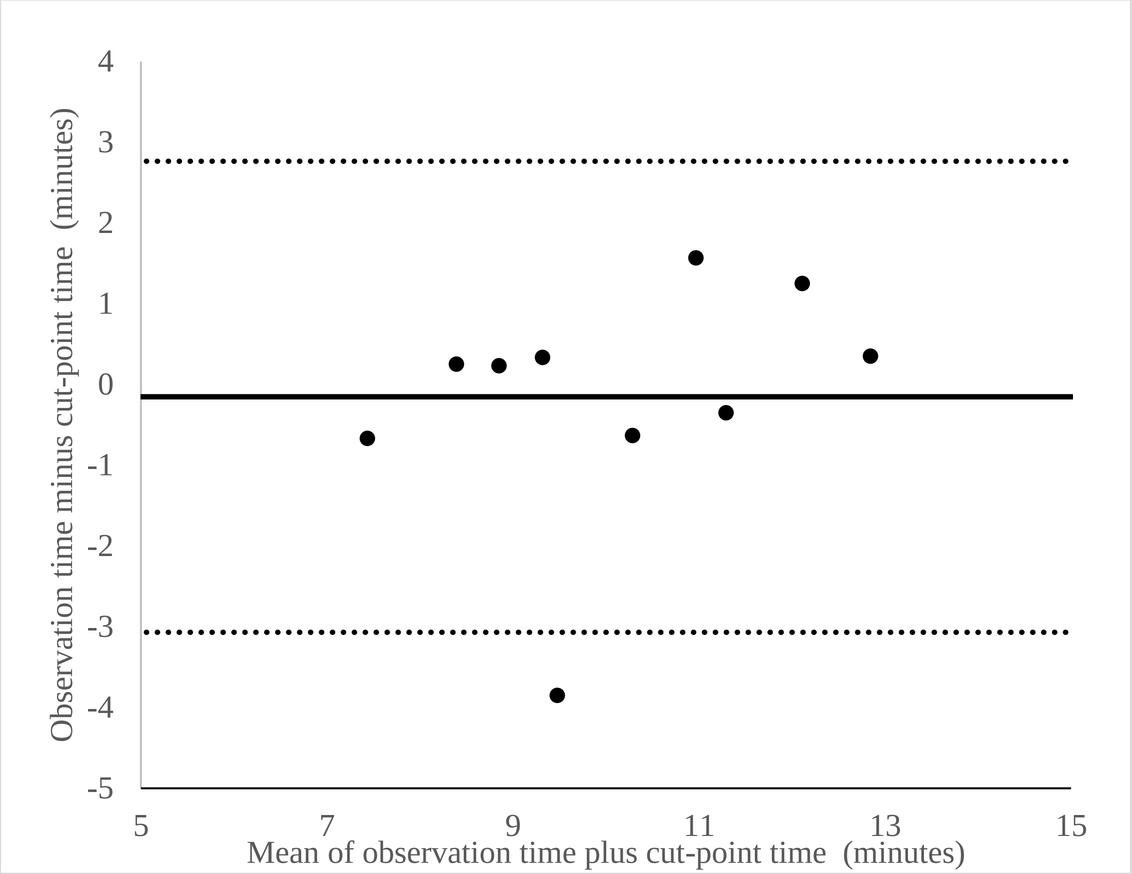
Phase 2 cut-point: ≥95&<325

Mean difference: -0.675

Upper limit of agreement: 1.991

Lower limit of agreement: -3.341

Supplementary Figure 25. Non-dominant wrist - Moderate to vigorous physical activity



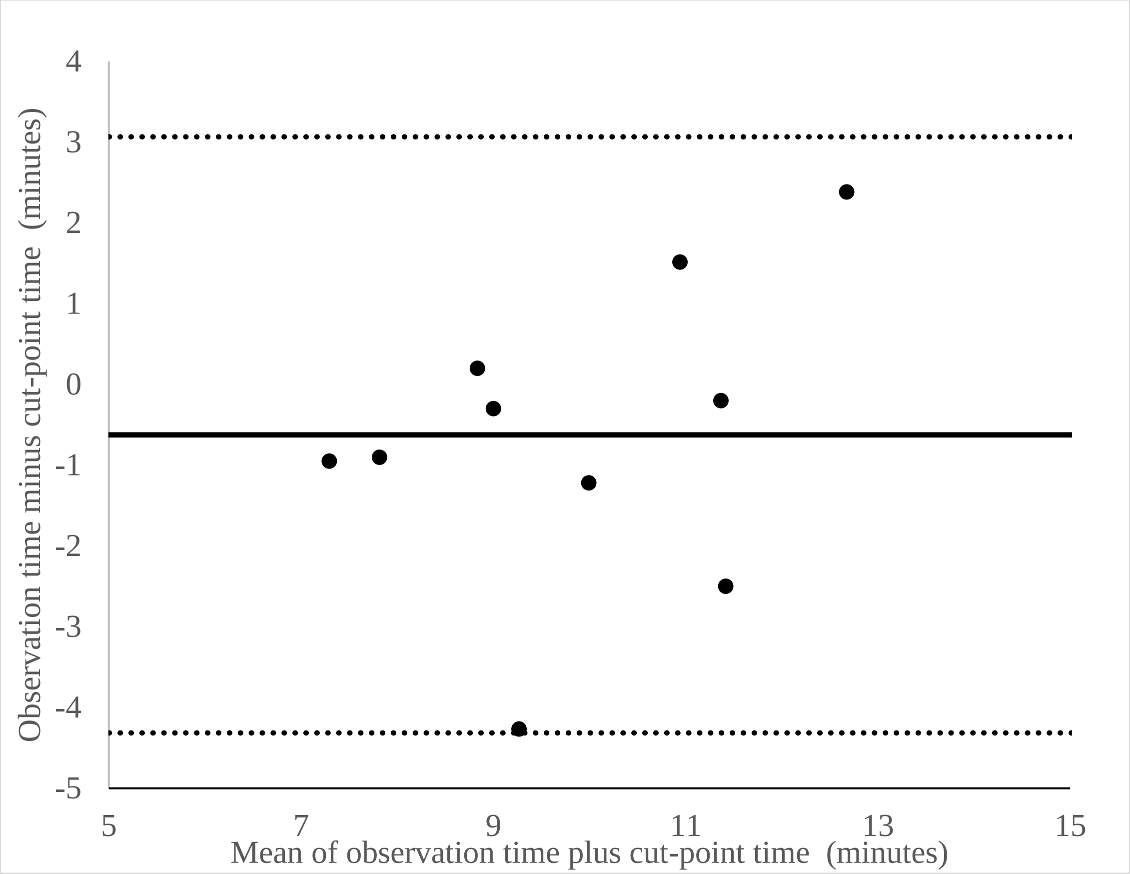
Phase 2 cut-point: ≥189

Mean difference: -0.152

Upper limit of agreement: 2.765

Lower limit of agreement: -3.068

Supplementary Figure 26. Dominant wrist - Moderate to vigorous physical activity



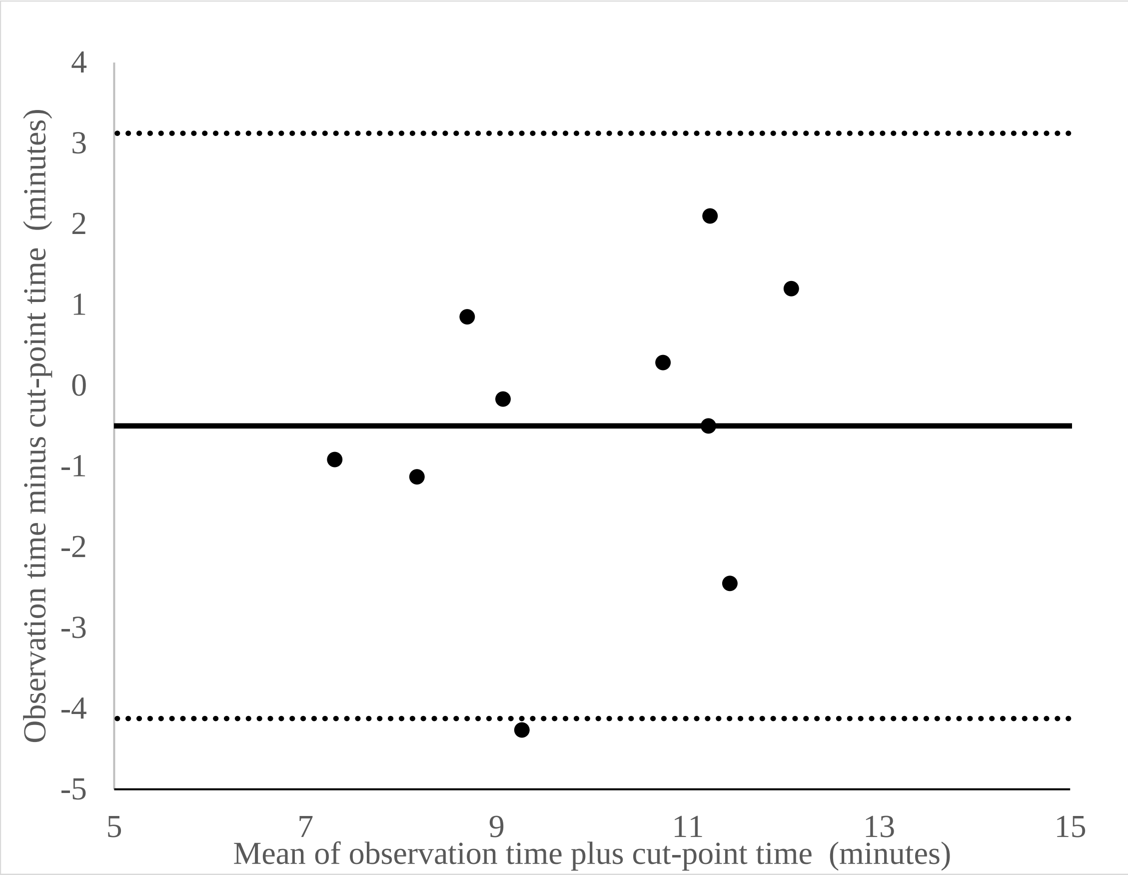
Phase 2 cut-point: ≥181

Mean difference: -0.623

Upper limit of agreement: 3.067

Lower limit of agreement: -4.314

Supplementary Figure 27. Hip - Moderate to vigorous Physical activity



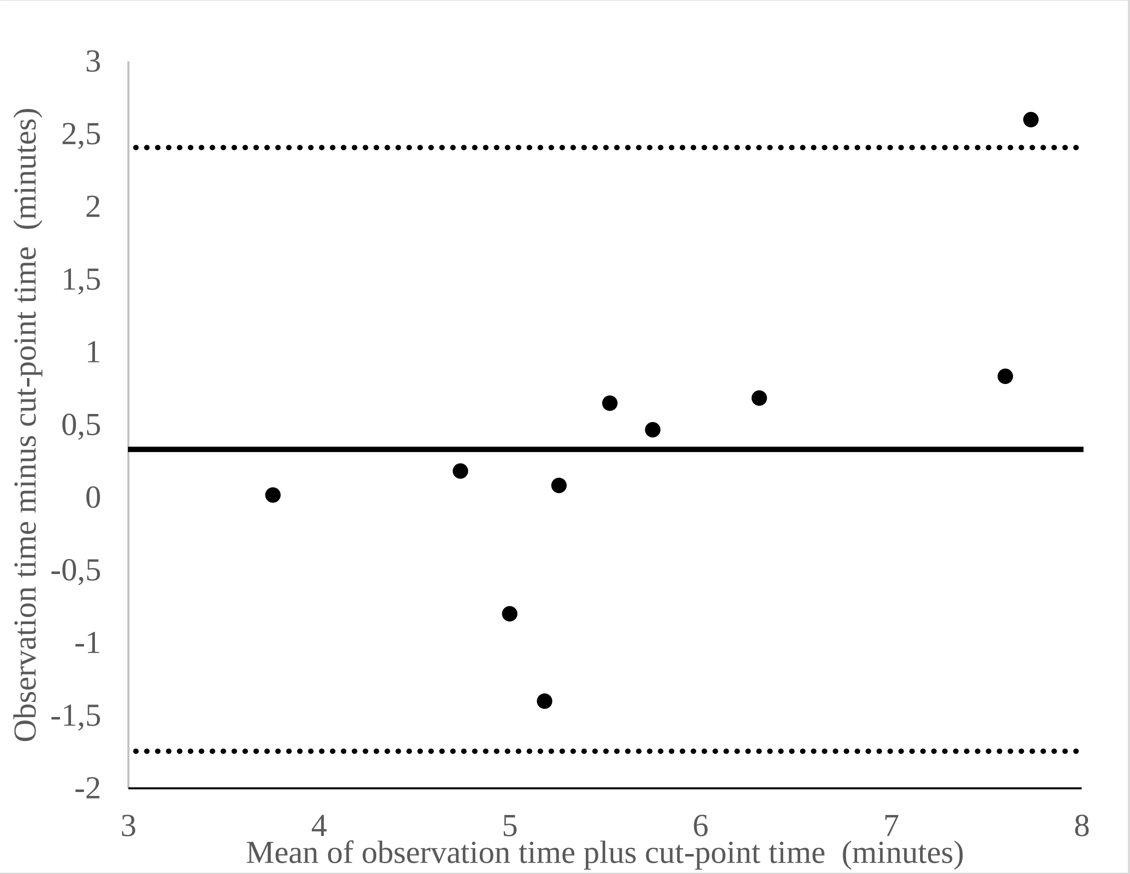
Phase 2 cut-point: ≥95

Mean difference: 1.849

Upper limit of agreement: 3.124

Lower limit of agreement: -4.124

Supplementary Figure 28. Non-dominant wrist - Vigorous physical activity



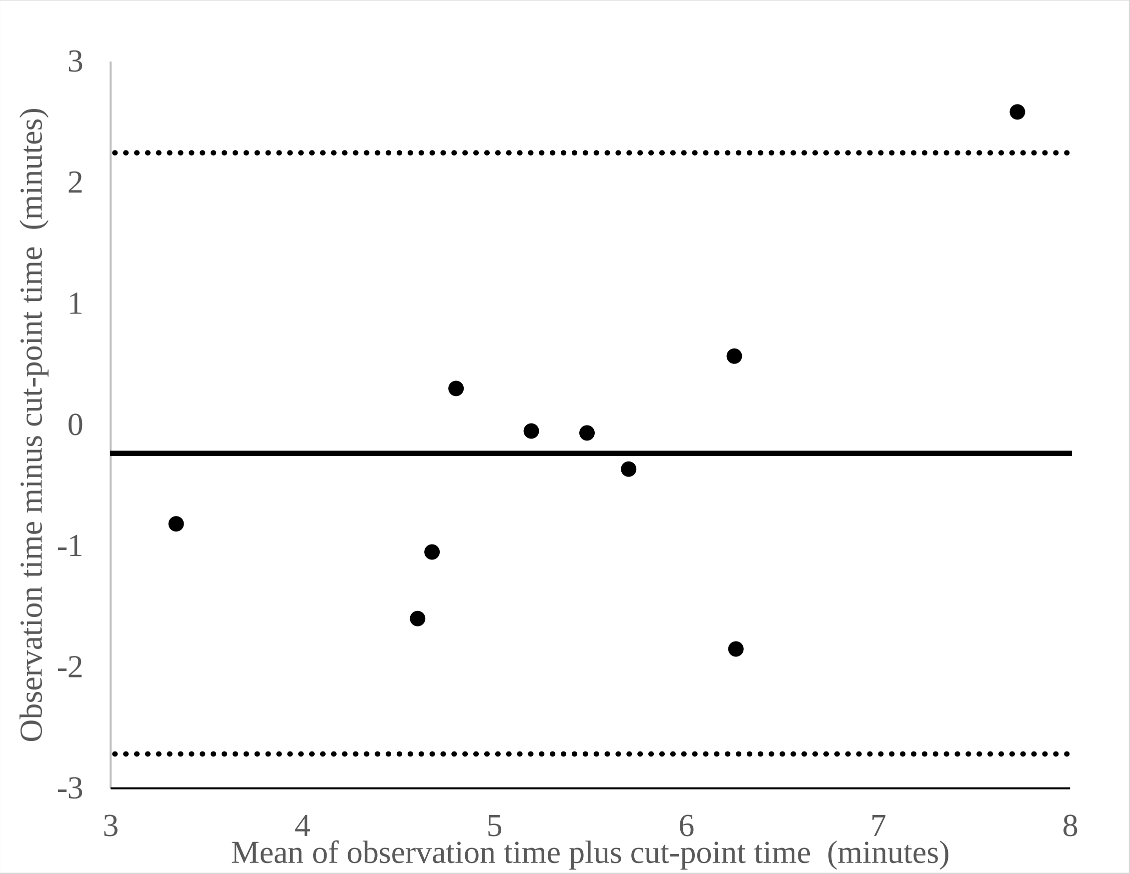
Phase 2 cut-point: ≥536

Mean difference: 0.332

Upper limit of agreement: 2.408

Lower limit of agreement: -1.745

Supplementary Figure 29. Dominant wrist - Vigorous physical activity



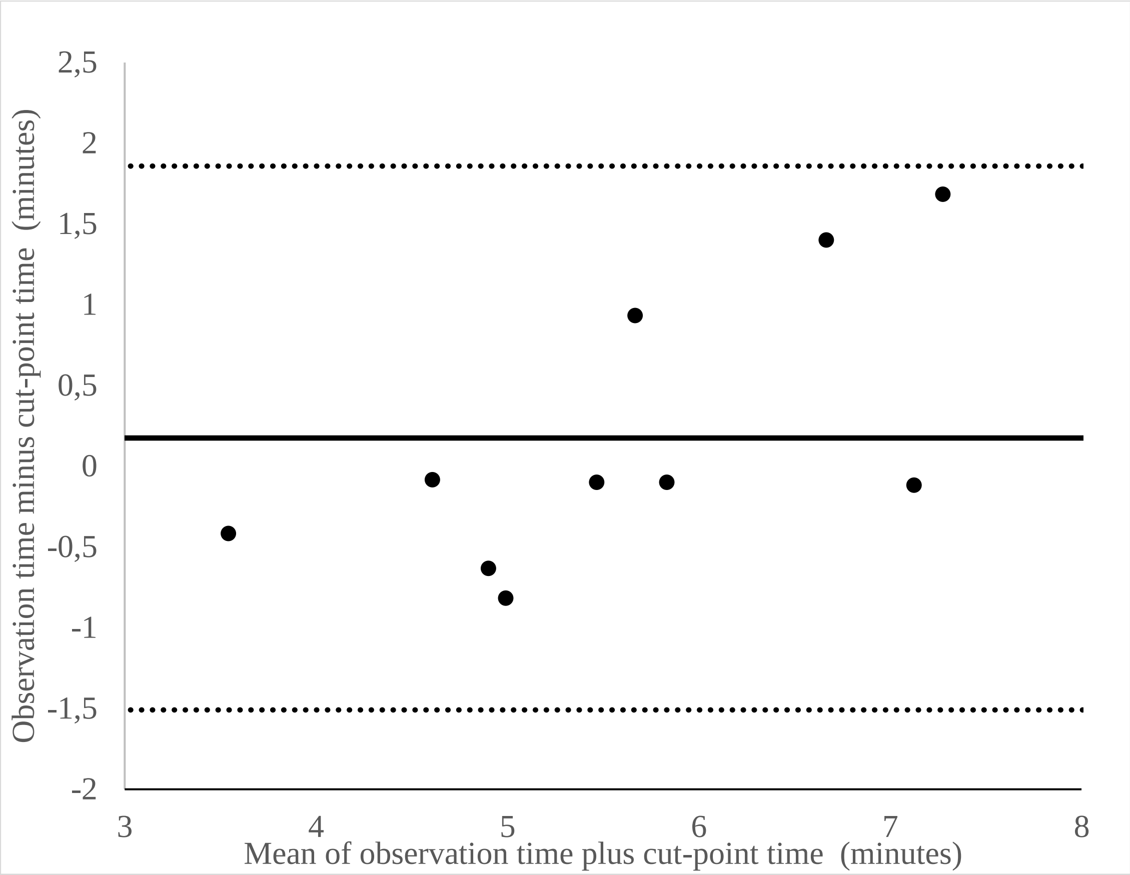
Phase 2 cut-point: ≥534

Mean difference: -0.235

Upper limit of agreement: 2.246

Lower limit of agreement: -2.716

Supplementary Figure 30. Hip - Vigorous physical activity



Phase 2 cut-point: ≥325

Mean difference: 0.175

Upper limit of agreement: 1.859

Lower limit of agreement: -1.509

Supplementary material 5. Table reporting inter-rater reliability results and the definition of each teaching practice in study 2

		Training		Main study	
	Definition	Percentage of agreement	Cohen's Kappa	Percentage of agreement	Cohen's Kappa
Lesson Context					
Management+	Lesson time when students are not involved in physical education content, including transition, management, and break times.	91.3	0.76	92.8	0.81
Knowledge-	Lesson time focused on student acquisition of knowledge related to physical education.	93.3	0.79	94.0	0.84
Motor Content+	Lesson time when students are engaged in activities involving motor content.	96.1	0.92	94.8	0.91
Fitness+	Activities where the main purpose is to warm-up or train cardiorespiratory fitness, strength and flexibility.	99.4	0.96	99.1	0.44
Skill Practice-	Activities where the main goal is to practice and improve movement skills.	97.2	0.90	94.1	0.90
Game Play+	Activities where movement skills are applied in game situations.	99.2	0.92	99.1	0.95
Free Play+	Time where children engage in play freely without the need of instruction.	99.7	0.96	N/A	N/A
*Discovery Practice+	Activities devoted to the exploration of different movement solutions to meet the task, to answer a question or to solve the problem proposed by the teacher.	97.8	0.94	99.4	0.97
Activity Context					
Individual Activity+	Students participate in an activity alone.	94.9	0.84	93.8	0.87
Partner Activity+	Students participate in an activity in pairs.	99.6	0.91	96.5	0.90

Small Sided Activity+	Students participate in activities divided into several small groups of not more than 5 children.	97.6	0.88	99.6	0.97
*Large Sided Activity-	Students participate in activities divided into groups of more than 5 children.	96.4	0.88	N/A	N/A
Whole Class Activity-	Students participate in activities as a large group and interact with each other to accomplish a goal.	90.5	0.81	92.5	0.87
Waiting Activity-	Activity where the majority of the children have to wait for their turn to play or participate.	91.7	0.76	91.8	0.54
Elimination Activity-	A game that involves the elimination of students from the activity.	99.7	0.96	N/A	N/A
Girls Only Activity+	Activities that only include girls.	99.2	0.96	N/A	N/A
Children Off Task-	Time when one or more students are not engaged in the task proposed by the teacher.	82.2	0.44	88.8	0.39
Teacher Behaviours					
*Supervises+	The teacher monitors the activity without intervening.	89.5	0.71	90.3	0.67
*Instructs Single Child-	Teacher interacts with one student either verbally or nonverbally providing either instructions, demonstration or feedback.	88.6	0.63	90.0	0.67
*Instructs Group-	Teacher interacts with a group of students either verbally or nonverbally providing either instructions, demonstration or feedback.	90.3	0.56	92.3	0.66
*Instructs Class-	Teacher interacts with the whole class either verbally or nonverbally providing either instructions, demonstration or feedback.	91.1	0.79	90.8	0.82
Promotes PA+	The teacher verbally promotes engagement in physical activity.	99.0	0.78	99.7	0.25

PA as Punishment-	When the teacher uses physical activity as a punishment for a misbehaviour.				
Withholding PA-	The teacher removes one or more students from an activity,	99.7	0.98	98.9	0.81
PA Engaged+	The teacher engages in physical activity together with the children.	99.4	0.77	97.7	0.71
Off Task-	The teachers engages in duties that are not related with the lesson.	97.0	0.71	97.8	0.66
Activity Management					
Signalling-	The teacher signals students to stop.	96.6	0.25	96.5	0.65
Retrieving equipment M-	Students move or collect equipment from/to multiple areas.	99.4	0.39	N/A	N/A
Retrieving equipment O-	Students move or collect equipment from/to one area.	99.2	0.76	98.5	0.33
Interruption Public-	Teacher addresses an interruption or misbehaviour publicly.	97.0	0.44	96.0	0.54
Interruption Private-	Teacher addresses an interruption or misbehaviour privately.	97.6	0.60	97.7	0.59
TOTAL AVERAGE		95.8	0.76	95.3	0.70

+ : Indicates that the teacher practice is theorised to foster engagement in moderate to vigorous physical activity.

- : Indicates that the teacher practice is theorised to hinder engagement in moderate to vigorous physical activity.

N/A: Indicates that the teacher variable was never observed.

PA: Physical activity.

*: indicates that the variable was introduced in this new version of the SOFIT+ teaching practices observation tool.

M: Multiple access points.

O: One access point.

Supplementary material 6. Linear pedagogy physical education lesson example

Linear Pedagogy curriculum: Object control skills - Lesson 1

	Key stage 1 Pupils should develop fundamental movement skills, become increasingly competent and confident and access a broad range of opportunities to extend their agility, balance and coordination, individually and with others. They should be able to engage in competitive (both against self and against others) and co-operative physical activities, in a range of increasingly challenging situations. ***Pupils should be taught to:*** - master basic movements including running, jumping, throwing and catching, as well as developing balance, agility and co-ordination, and begin to apply these in a range of activities. - participate in team games, developing simple tactics.
B3*: *Lesson No	**Lesson 1**
Lesson Outcome	Demonstrate mastery over underarm throw.
Desired outcome	To be able to perform an underarm roll at for accuracy while stationary and while moving.
Progression based on Gentiles' taxonomy	**Foster children motor skills learning by Increasing the difficulty of the task over the lessons using Gentile's taxonomy:** **Body: from no body transport → to body transport** **Object: from no object → to manipulation of object** **Motion: from object still → to object moving** **Intertrial Variability: from no intertrial variability → to intertrial variability**
B8: Whole Class Task Activity	**Warm up** The orchestra Children must imitate the teacher who is the orchestra leader. • Open and close arms on horizontal plane and clap hands. • Hands close to the ground and then up over the head. • Claps hands on the legs. • Alternate one clap on legs and one with hands. • Alternate one clap on the chest and one with hands. • Clap hands behind the back and on the front • Claps on the floor.

Alternate claps.

The teacher divides children in groups, each group will perform a different clap. When the director of the orchestra (teacher) gives the signal children start clapping.

Drill 1

<u>Simplification of underarm roll</u>

Demonstration: The teacher swings an arm from back to front as a pendulum and uses a verbal cue to guide the speed. Children are asked to say "swing back and swing forward" while performing the movement.

Subsequently, the teacher demonstrates how to bend and get close to the floor while swinging the arm:

"Step forward and caress the grass".

Last the last demonstration the teacher includes a step forward in the action:

"Swing back step forward and caress the grass ".

Drill 2a

After performing drill 1 one correctly each child receives a ball.

Child will repeat the drill one:

"Swing back step forward and caress the grass ".

With a ball in their hand.

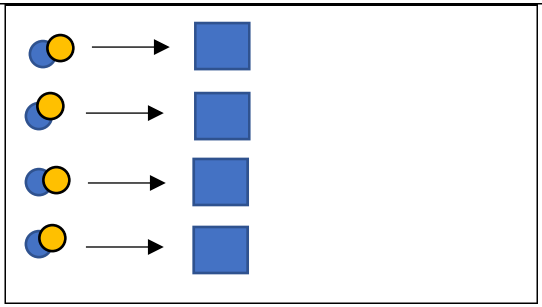
Drill 2b

Children repeat drill 2a throwing the ball to a goal.

Each child is responsible for one ball and must collect it after throwing it. The target might be placed close to a wall, so the ball does not roll far. Alternatively, children could work in pairs: a child could stand with leg open, and another child could roll the ball between the legs of the companion (goal).

→ Throw

■ Target



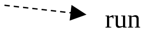
Drill 2c

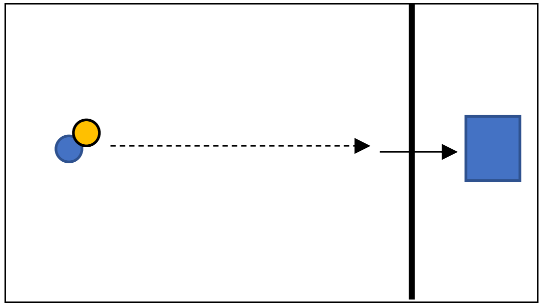
Same as drill 2b but children use different balls/ different targets. Possible gamification, the pair of children that scores the highest number of goals will win (set a precise distance).

Drill 3

Children are asked to walk towards a target and perform an underarm roll without stopping. Subsequently, children are be asked to run and perform an underarm roll towards a target while running.

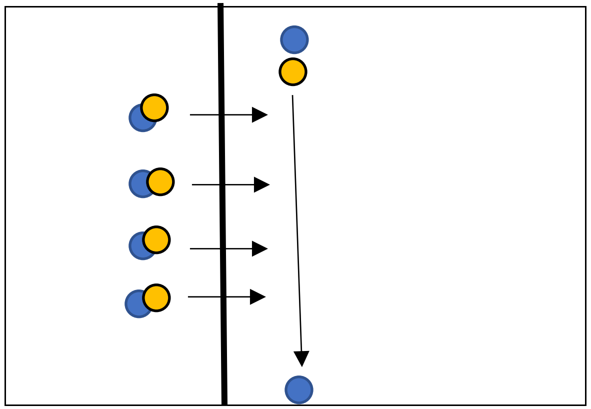
The drill becomes a relay: the team that scores more goals wins. The rules are the following: only a child per team can run.





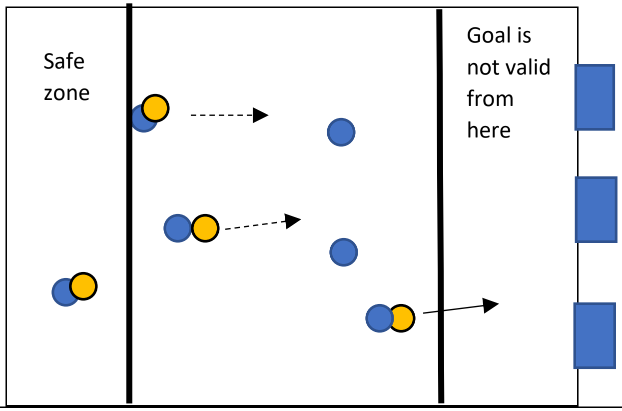
Drill 4

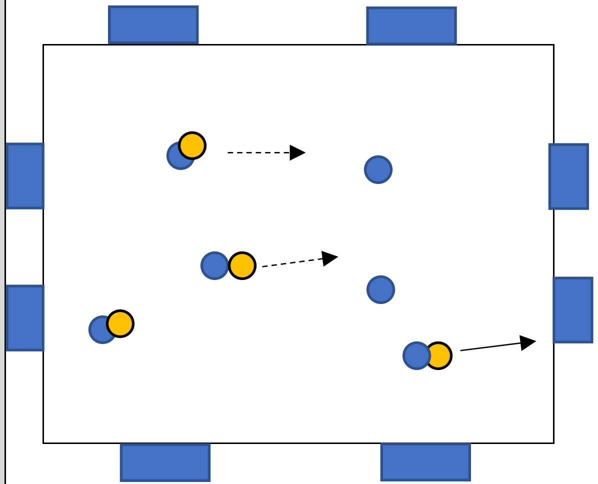
The teacher devides children in groups. Two children roll a ball in front of the rest of a group of children. The other children will try to hit the rolling ball using small balls.



Game

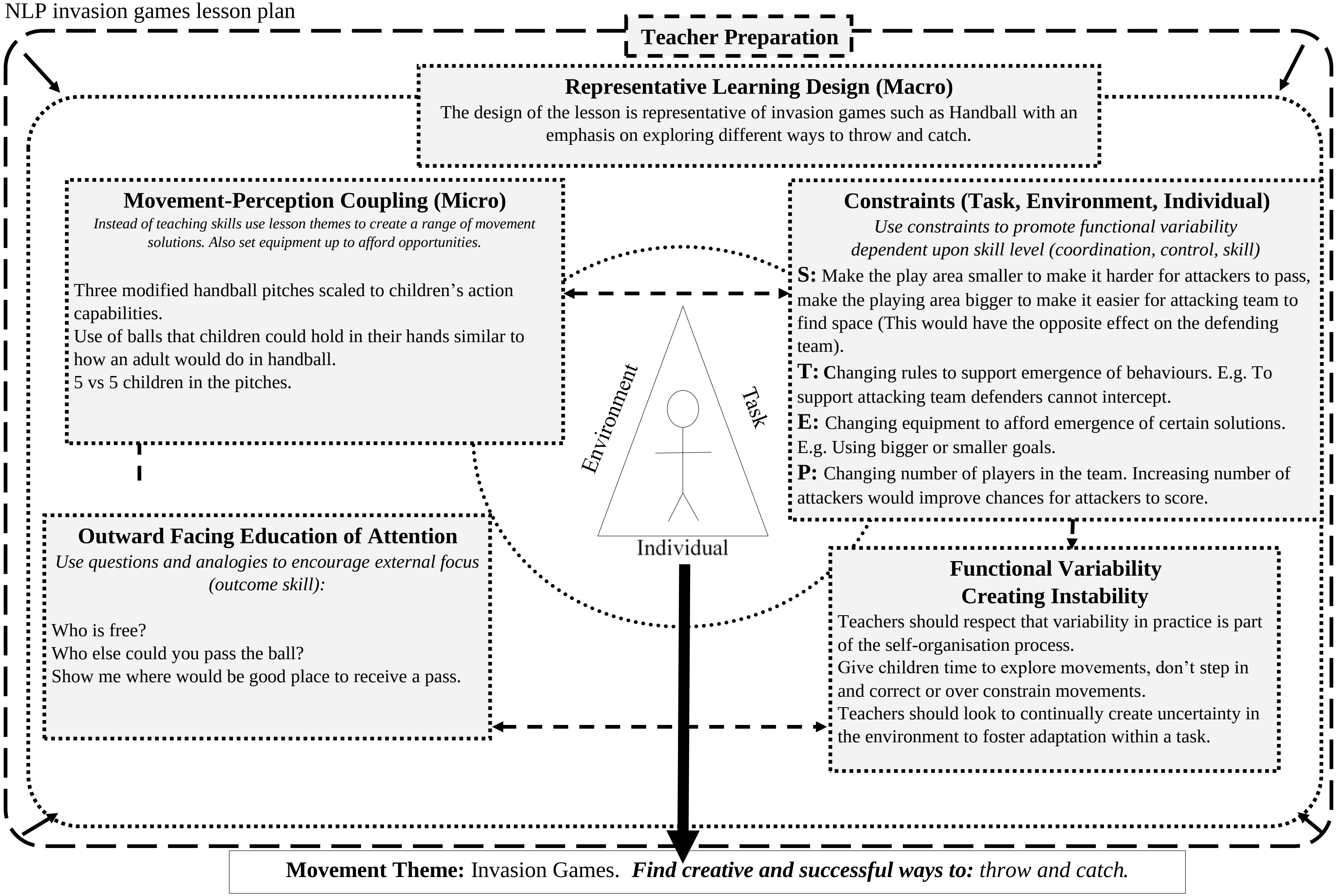
Children are provided with balls within a safe zone and they have to hit in the targets on the other side of the hall. However, other children will try to stop them by tagging them. The children that get tagged must come back to the safe zone before attempting to score a goal again. It is not possible to throw from the safe zone. Only underarm throw is valid.



	Alternative game <u>Stuck in the mud</u> If children get tagged, they must roll their ball to a target. If they miss it, they are stuck and they must wait for a mate to free them. To free children who are stuck other children must roll a ball between their legs. If the task is too complex, the teacher removes the targets.  **Cool down** Walking around the space, quietly. Take a seat. The teacher asks questions about the lesson.

Supplementary material 7. Nonlinear pedagogy physical education lesson example

NLP invasion games lesson plan



Supplementary material 8. Pedagogical fidelity checklist in study 3 and study 4

School	Lesson Type		Lesson Duration (Divide by 4 to work out quartiles)	Quartiles			
	Pedagogy A	**Sliding Scale**	**Pedagogy B**	**Q1**	**Q2**	**Q3**	**Q4**
1	**To support learning of fundamental movement skills PE teacher/coach will manipulate the child's movements through breaking the skill into component parts**	**1 2 3 4 5**	**To support the emergence of functional movement solutions the PE teacher/coach will manipulate the task or environment but not the child.**				
2	**Children learn skill first in closed decontextualized environments then apply new skills in a performance environment**	**1 2 3 4 5**	**Movements are always learnt in context (music, storytelling, scenarios or games).**				
3	**All children transition between activities and task at roughly the same time.**	**1 2 3 4 5**	**Transitions may be whole class, group of children or individual child and involve manipulations of tasks and activities but could on the surface be quite minor.**				
4	**PE teacher/coach controls what equipment is used and when it is introduced to the children.**	**1 2 3 4 5**	**PE teacher/coach allows the children to choose which equipment to use and when they want to use it to help with finding solution to the task.**				
Teaching Behaviours							
1	**Demonstrations of fundamental movement skill by adult or a competent child is preferred option in closed environment**	**1 2 3 4 5**	**Demonstration are done in context to encourage children to explore unique performance solutions**				
2	**The use of verbal instruction is prescriptive and focused on correct technical movement pattern**	**1 2 3 4 5**	**Verbal instruction is short and not prescriptive, focused on the environment or task.**				
3	**Feedback is skill focused and prescriptive to learn ideal template**	**1 2 3 4 5**	**Feedback is used to support alternative functional movement solutions.**				

Lesson Objectives		**Sliding Scale** **1 2 3 4 5**	
A Global	**Teacher prescribes children to perform fundamental movement skill or set of fundamental movement skills.** **Children learn an optimal movement template or technique of a particular skill or series of skills**	**1 2 3 4 5**	**Teacher creates an environment for children to perform functional movement solutions through interaction with the environment and task.** **Children learn to explore and interact with their environment to find functional solutions**
B Global	**Lesson progression is through clear and linear structure, warm up, drills, game/performance and cool down.**	**1 2 3 4 5**	**Lesson evolves through storytelling, scenarios or games.**

Supplementary material 9. Reasons for missing physical activity data in study 4

	Linear Pedagogy N children = 105	Nonlinear Pedagogy N children = 112	Control N children = 143
Baseline			
Child was absent	6	6	4
Child lost the accelerometer	1		3
Child did not want to wear an accelerometer	1	3	1
Did not meet valid wear time inclusion criteria	10	23	40
Valid physical activity observation	87	80	95
Post-intervention			
Child was absent	3	1	1
Child lost the accelerometer	2	3	4
Child moved to another school	1	2	5
Child did not want to wear an accelerometer	2	3	2
Did not meet valid wear time inclusion criteria	34	28	60
Valid physical activity observation	63	75	71
Follow-up			
Child was absent	4	4	2
Child lost the accelerometer	2	3	
Accelerometer technical problem		1	
Child moved to another school	2	6	19
Child did not want to wear an accelerometer	1	1	3
Child did not receive accelerometer a she or she still had to return one	3	4	5
Did not meet valid wear time inclusion criteria	31	33	55
Valid physical activity observation	62	60	59

Supplementary material 10. Descriptive data for all variables of study 4

Table reporting baseline data

	Control (143 children)			**Nonlinear Pedagogy**			**Linear Pedagogy**		
Variables	**Mean**	**/SD**	**Missing**	**Mean**	**/SD**	**Missing**	**Mean**	**/SD**	**Missing**
Sex (Females)	83		0	58		0	56		0
Decimal Age (years)	5.94	0.29	2	5.92	0.30	1	5.95	0.30	5
White British	69		5	54		9	66		8
SEN (Special Educational Needs)	17		0	17		1	8		1
IMD Deprivation Decile (arbitrary units)	1.73	1.51	3	2.52	2.05	1	1.43	1.20	4
IOTF SDS BMI (arbitrary units)	0.33	1.08	28	0.51	1.11	8	0.43	1.34	9
Participation in school sport events	0		0	0		0	0		0
Whole week valid hours (hours)	16.36	0.94	48	16.18	1.17	32	16.34	1.11	18
Whole week MVPA (minutes)	68.08	18.51	48	68.84	20.31	32	69.33	19.37	18
Whole week Mean ENMO (milligravity)	60.41	13.21	48	60.31	14.30	32	61.88	14.58	18
Whole week M60 (milligravity)	214.36	66.80	48	206.27	67.70	32	219.13	81.67	18
Weekend valid hours (hours)	16.15	1.59	48	16.11	1.64	32	16.08	1.70	18
Weekend MVPA (minutes)	63.18	27.76	48	63.21	27.09	32	65.14	28.30	18
Weekend Mean ENMO (milligravity)	55.08	20.51	48	54.07	19.060	32	57.36	20.95	18
Weekend M60 (milligravity)	200.65	114.07	48	192.17	98.55	32	217.27	142.07	18
In school valid hours (hours)	5.97	0.21	48	5.98	0.11	32	5.95	0.29	18
In school MVPA (minutes)	34.26	11.72	48	35.38	10.79	32	31.95	9.78	18
In school mean ENMO (milligravity)	89.05	24.91	48	90.62	22.80	32	84.03	23.77	18
In school M30 (milligravity)	198.83	119.80	48	206.32	114.24	32	228.61	134.24	18
Out of school valid hours (hours)	7.59	0.74	48	7.38	0.97	32	7.60	0.74	18
Out of school MVPA (minutes)	28.61	9.06	48	28.32	10.43	32	31.47	11.86	18
Out of school mean ENMO (milligravity)	52.48	14.40	48	51.95	15.31	32	57.52	19.42	18
Out of school M30 (milligravity)	145.53	52.92	48	146.72	56.03	32	164.50	73.87	18
Whole week Temperature (Celsius degrees)	2.62	2.10	48	5.86	1.68	32	5.08	0.65	18
Whole week Rainfall (mm water)	1.67	1.99	48	3.53	1.50	32	3.44	1.78	18
Whole week percentage of daylight (%)	39.02	4.75	48	35.20	1.54	32	33.71	0.75	18
During the week Temperature (Celsius	2.29	2.80	48	5.67	1.03	32	5.30	0.34	18
During the week Rainfall (mm water)	1.46	1.69	48	2.76	1.78	32	1.98	2.26	18
During the week percentage of daylight (%)	39.09	4.89	48	35.03	1.59	32	33.52	0.75	18
Weekend Temperature (Celsius degrees)	3.16	1.18	48	6.39	2.90	32	4.68	1.44	18
Weekend Rainfall (mm water)	2.12	2.94	48	4.71	1.86	32	5.87	1.89	18
Weekend percentage of daylight (%)	39.91	4.53	48	35.45	1.48	32	33.99	0.77	18
Meeting guidelines		%			%			%	
Meeting guidelines whole week	59	62.11	48	51	63.75	32	59	67.82	18
Meeting guidelines week	68	71.58	48	57	71.25	32	61	70.11	18
Meeting guidelines weekend	50	52.63	48	38	47.50	32	46	52.87	18
Reaching 30 minutes of MVPA in school	56	58.95	48	54	67.50	32	48	55.17	18
Reaching 30 minutes of MVPA outside school	42	44.21	48	37	46.25	32	47	54.02	18

MVPA: Moderate to vigorous physical activity; **ENMO**: Euclidean norm minus one; **M60:** minimum acceleration in the most active hour; **M30:** minimim acceleration in the most active half hour; **SD:** standard error; **IMD:** index of neighbourhood multiple deprivation decile; **IOTF SDS BMI:** International Obesity Task Force standardised Body Mass Index.

Table reporting post-intervention data

Variables	Control (143 children) Mean Number	/SD	Missing data	Nonlinear Pedagogy Mean Number	/SD	Missing data	Linear Pedagogy Mean Number	/SD	Missing data
Sex (Females)	83		0	58		0	56		0
Decimal Age (years)	6.37	0.28	2	6.34	0.30	1	6.37	0.30	5
White British	69		5	54		9	66		8
SEN (Special Educational Needs)	17		0	17		1	8		1
IMD Deprivation Decile (arbitrary units)	1.73	1.51	3	2.52	2.05	1	1.43	1.20	4
IOTF SDS BMI (arbitrary units)	-0.01	1.37	19	0.01	1.22	9	0.19	1.37	6
Participation in school sport events	0		0	0		0	59		0
Whole week valid hours (hours)	15.83	1.33	72	15.93	1.19	37	16.10	1.06	42
Whole week MVPA (minutes)	83.69	20.86	72	84.10	24.38	37	89.73	27.92	42
Whole week Mean ENMO (milligravity)	73.13	17.07	72	73.84	19.32	37	77.60	20.99	42
Whole week M60 (milligravity)	261.53	78.65	72	256.10	79.26	37	280.31	85.57	42
Weekend valid hours (hours)	15.57	1.77	72	15.93	1.43	37	16.08	1.23	42
Weekend MVPA (minutes)	78.56	31.76	72	78.92	31.72	37	82.84	30.70	42
Weekend Mean ENMO (milligravity)	66.31	26.11	72	67.95	24.71	37	68.50	21.58	42
Weekend M60 (milligravity)	222.92	116.36	72	239.01	100.92	37	242.87	98.44	42
In school valid hours (hours)	5.93	0.32	72	5.96	0.16	37	5.97	0.10	42
In school MVPA (minutes)	40.51	10.64	72	40.54	11.41	37	44.37	12.31	42
In school mean ENMO (milligravity)	108.42	29.72	72	106.04	29.62	37	115.34	28.80	42
In school M30 (milligravity)	231.21	126.08	72	224.71	118.23	37	214.44	98.11	42
Out of school valid hours (hours)	7.28	1.02	72	7.23	1.04	37	7.34	0.90	42
Out of school MVPA (minutes)	38.28	14.96	72	37.90	15.92	37	39.33	20.22	42
Out of school mean ENMO (milligravity)	67.23	22.92	72	68.07	26.51	37	69.80	32.17	42
Out of school M30 (milligravity)	249.73	94.08	72	262.70	111.32	37	257.91	119.90	42
Whole week Temperature (Celsius degrees)	18.43	1.78	72	18.25	1.52	37	19.04	1.77	42
Whole week Rainfall (mm water)	1.07	0.80	72	0.56	0.86	37	1.33	0.74	42
Whole week percentage of daylight (%)	70.39	0.44	72	70.50	0.45	37	70.20	0.52	42
During the week Temperature (Celsius	18.81	1.81	72	19.08	1.86	37	18.85	1.61	42
During the week Rainfall (mm water)	0.60	0.71	72	0.47	0.70	37	0.72	1.08	42
During the week percentage of daylight (%)	70.35	0.46	72	70.48	0.44	37	70.15	0.51	42
Weekend Temperature (Celsius degrees)	17.72	2.45	72	16.98	2.30	37	19.35	2.29	42
Weekend Rainfall (mm water)	1.86	1.63	72	0.73	1.23	37	2.38	1.48	42
Weekend percentage of daylight (%)	70.48	00.49	72	70.52	0.53	37	70.28	0.56	42
Meeting guidelines		%			%			%	
Meeting guidelines whole week	64	90.14	72	64	85.33	37	56	88.89	42
Meeting guidelines week	66	92.96	72	68	90.67	37	55	87.30	42
Meeting guidelines weekend	51	71.83	72	52	69.33	37	49	77.78	42
Reaching 30 minutes of MVPA in school	62	87.32	72	65	86.67	37	57	90.48	42
Reaching 30 minutes of MVPA outside school	49	69.01	72	47	62.67	37	42	66.67	42

MVPA: Moderate to vigorous physical activity; **ENMO**: Euclidean norm minus one; **M60:** minimum acceleration in the most active hour; **M30:** minimum acceleration in the most active half hour; **SD:** standard error; **IMD:** index of neighbourhood multiple deprivation decile; **IOTF SDS BMI:** International Obesity Task Force standardised Body Mass Index.

Table reporting follow-up data

Variables	Control (143 children) Mean Number	/SD	Missing data	Nonlinear Mean Number	/SD	Missing data	Linear Pedagogy Mean Number	/SD	Missing data
Sex (Females)	83		0	58		0	56		0
Decimal Age (years)	6.96	0.28	1	6.94	0.30	0	6.96	0.30	5
White British	69		5	54		9	66		8
SEN (Special Educational Needs)	17		0	17		1	8		1
IMD Deprivation Decile (arbitrary units)	1.73	1.51	3	2.52	2.05	1	1.43	1.20	4
IOTF SDS BMI (arbitrary units)	0.23	1.46	26	0.18	1.33	10	0.30	1.45	9
Participation in school sport events	0		0	0		0	0		0
Whole week valid hours (hours)	15.97	1.19	84	16.31	0.80	52	15.70	1.11	43
Whole week MVPA (minutes)	62.59	16.00	84	72.76	16.79	52	66.25	18.63	43
Whole week Mean ENMO (milligravity)	56.86	12.29	84	63.64	11.74	52	60.25	14.75	43
Whole week M60 (milligravity)	217.30	79.03	84	216.52	63.90	52	220.17	85.55	43
Weekend valid hours (hours)	15.82	1.59	84	16.21	1.29	52	15.96	1.59	43
Weekend MVPA (minutes)	52.36	21.07	84	65.39	23.24	52	60.95	21.99	43
Weekend Mean ENMO (milligravity)	46.56	14.43	84	56.76	15.97	52	53.10	15.81	43
Weekend M60 (milligravity)	156.60	69.42	84	189.33	93.57	52	192.97	100.25	43
In school valid hours (hours)	5.98	0.07	84	5.95	0.11	52	5.97	0.11	43
In school MVPA (minutes)	32.86	11.47	84	37.09	9.30	52	31.85	10.39	43
In school mean ENMO (milligravity)	89.16	31.39	84	93.32	20.50	52	86.45	26.51	43
In school M30 (milligravity)	159.51	80.48	84	190.96	96.44	52	207.44	113.53	43
Out of school valid hours (hours)	7.30	1.00	84	7.52	0.64	52	6.85	0.88	43
Out of school MVPA (minutes)	27.13	10.09	84	31.11	11.97	52	27.89	11.49	43
Out of school mean ENMO (milligravity)	50.66	16.72	84	56.96	17.85	52	53.19	19.40	43
Out of school M30 (milligravity)	191.50	80.81	84	214.30	90.65	52	201.39	98.55	43
Whole week Temperature (Celsius degrees)	7.85	0.66	84	7.28	0.81	52	6.15	2.05	43
Whole week Rainfall (mm water)	5.56	3.47	84	1.70	0.83	52	3.78	2.03	43
Whole week percentage of daylight (%)	42.48	6.62	84	38.53	4.52	52	38.55	4.56	43
During the week Temperature (Celsius	7.47	1.01	84	7.08	1.18	52	5.49	2.62	43
During the week Rainfall (mm water)	5.52	3.84	84	1.56	1.03	52	3.44	2.10	43
During the week percentage of daylight (%)	42.65	0.07	84	37.58	4.64	52	38.70	4.61	43
Weekend Temperature (Celsius degrees)	8.68	0.98	84	7.76	1.44	52	7.82	1.21	43
Weekend Rainfall (mm water)	5.62	3.30	84	2.03	1.36	52	4.77	3.49	43
Weekend percentage of daylight (%)	42.18	6.34	84	37.47	4.37	52	38.19	4.54	43
Meeting guidelines		%			%			%	
Meeting guidelines whole week	33	55.93	84	50	83.33	52	38	61.29	43
Meeting guidelines week	37	62.71	84	53	88.33	52	40	64.52	43
Meeting guidelines weekend	22	37.29	84	30	50.00	52	29	46.77	43
Reaching 30 minutes of MVPA in school	31	52.54	84	46	76.67	52	34	54.84	43
Reaching 30 minutes of MVPA outside school	23	38.98	84	30	50.00	52	26	41.94	43

MVPA: Moderate to vigorous physical activity; **ENMO**: Euclidean norm minus one; **M60:** minimum acceleration in the most active hour; **M30:** minimum acceleration in the most active half hour; **SD:** standard error; **IMD:** index of neighbourhood multiple deprivation decile; **IOTF SDS BMI:** International Obesity Task Force standardised Body Mass Index.

Table reporting whole sample pooled data

Row Labels	Whole sample			
	Mean Number	**/SD**	**Valid data**	**Missing Data**
Sex (Females)	197		1080	0
Decimal Age (years)	6.60	4.37	1056	24
White British	189		1014	66
SEN (Special Educational Needs)	42		1074	6
IMD Deprivation Decile (arbitrary units)	1.89	1.68	1056	24
IOTF SDS BMI (arbitrary units)	0.24	1.31	956	124
Participation in school sport events	0		1080	0
Whole week valid hours (hours)	16.10	1.12	652	428
Whole week MVPA (minutes)	73.74	22.21	652	428
Whole week Mean ENMO (milligravity)	65.15	16.94	652	428
Whole week M60 (milligravity)	231.29	79.77	652	428
Weekend valid hours (hours)	16.00	1.56	652	428
Weekend MVPA (minutes)	67.84	28.89	652	428
Weekend Mean ENMO (milligravity)	58.46	21.49	652	428
Weekend M60 (milligravity)	206.99	109.64	652	428
In school valid hours (hours)	5.96	0.19	652	428
In school MVPA (minutes)	36.37	11.59	652	428
In school mean ENMO (milligravity)	95.33	28.29	652	428
In school M30 (milligravity)	208.27	115.25	652	428
Out of school valid hours (hours)	7.36	0.91	652	428
Out of school MVPA (minutes)	32.14	13.81	652	428
Out of school mean ENMO (milligravity)	58.48	21.97	652	428
Out of school M30 (milligravity)	199.69	97.44	652	428
Whole week Temperature (Celsius degrees)	9.69	6.45	652	428
Whole week Rainfall (mm water)	2.47	2.28	652	428
Whole week percentage of daylight (%)	48.02	15.9	652	428
During the week Temperature (Celsius degrees)	9.64	6.77	652	428
During the week Rainfall (mm water)	1.97	2.37	652	428
During the week percentage of daylight (%)	48.01	15.91	652	428
Weekend Temperature (Celsius degrees)	9.86	6.12	652	428
Weekend Rainfall (mm water)	3.34	2.88	652	428
Weekend percentage of daylight (%)	48.03	15.89	652	428
Meeting guidelines		%		
Meeting guidelines whole week	474	72.70	652	428
Meeting guidelines week	505	77.45	652	428
Meeting guidelines weekend	367	56.29	652	428
Reaching 30 minutes of MVPA in school	453	69.48	652	428
Reaching 30 minutes of MVPA outside school	343	52.61	652	428

MVPA: Moderate to vigorous physical activity; **ENMO**: Euclidean norm minus one; **M60:** minimum acceleration in the most active hour; **M30:** minimum acceleration in the most active half hour; **SD:** standard error; **IMD:** index of neighbourhood multiple deprivation decile; **IOTF SDS BMI:** International Obesity Task Force standardised Body Mass Index.

Supplementary material 11. Intention to treat analysis results in study 4

Whole week physical activity

	MVPA			Mean ENMO			M60		
Predictors	**Estimate**	**Std. error**	**p-value**	**estimate**	**Std. error**	**p-value**	**Estimate**	**Std error**	**p-value**
(Intercept)	-18.75	24.75	0.454	-7.889	14.908	0.598	128.752	79.585	0.111
Time [T1 Vs T0]	-4.00	3.90	0.318	-2.997	3.088	0.345	-12.608	11.046	0.262
Time [T2 Vs T0]	-6.59	4.60	0.163	-5.604	2.940	0.062	-13.141	12.777	0.306
Group [NLP Vs Control]	2.14	3.22	0.509	0.795	2.332	0.734	-14.335	12.029	0.238
Group [LP Vs Control]	3.16	2.86	0.269	1.700	2.391	0.479	-3.962	11.166	0.723
Decimal Age	5.19	3.45	0.141	5.084	2.116	0.017	10.603	11.332	0.353
Sex	-12.10	2.07	<0.001	-9.335	1.446	<0.001	-54.850	7.887	<0.001
IOTF SDS BMI	-0.72	0.84	0.403	-0.941	0.596	0.124	-5.407	2.671	0.049
Special educational needs	-1.20	3.90	0.760	-1.282	2.176	0.556	-15.054	11.926	0.209
Index of multiple deprivation	-0.29	0.60	0.629	-0.196	0.515	0.705	-0.179	2.360	0.940
Ethnicity code	1.77	1.97	0.370	4.304	1.608	0.009	22.100	9.184	0.022
Sport events	1.49	4.00	0.711	2.718	3.307	0.417	13.902	13.505	0.308
Mean rainfall (mm rain)	-0.94	0.43	0.043	-0.849	0.255	0.002	-2.648	1.005	0.010
Mean Temperature (Celsius degrees)	0.25	0.30	0.414	0.244	0.246	0.333	2.053	1.106	0.076
Daylight (% of day duration)	0.48	0.15	0.006	0.325	0.099	0.003	0.710	0.410	0.094
Valid wear time	2.78	0.71	0.001	1.894	0.523	0.001	1.483	2.364	0.535
Time [T1] * Group [NLP] Vs Control	-2.62	3.17	0.414	-1.881	2.652	0.483	-1.805	10.466	0.864
Time [T2] * Group [NLP] Vs Control	1.57	3.75	0.680	0.402	2.448	0.870	3.156	11.981	0.794
Time [T1] * Group [LP] Vs Control	-0.64	4.04	0.876	-0.936	2.850	0.743	-0.071	14.383	0.996
Time [T2] * Group [LP] Vs Control	-2.07	3.33	0.538	-2.204	2.539	0.390	-1.692	11.085	0.879
Random Effects									
σ2	160.87			100.49			1948.89		
τ00 Children	213.53			110.92			3008.79		
Intraclass correlation coefficient	0.57			0.52			0.61		
Number of children	360			360			360		
Observations	1080			1080			1080		
Marginal R2 / Conditional R2	0.24/0.67			0.26/0.65			0.22/0.69		

MVPA: Moderate to vigorous physical activity; **ENMO**: Euclidean norm minus one; **M60:** minimum acceleration in the most active hour; **Std. error:** standard error; **T0:** Baseline; **T1:** Post Intervention **T2:** Follow-up; **NLP:** Nonlinear Pedagogy group; **LP:** Linear Pedagogy group; **IOTF SDS BMI:** International Obesity Task Force standardised Body Mass Index, **σ2:** Intercept variance; **τ00:** Random factor variance

Weekend physical activity

Predictors	MVPA Estimate	Std. error	p-value	Mean ENMO estimate	Std. error	p-value	M60 Estimate	Std error	p-value
(Intercept)	-60.06	25.31	0.019	-25.92	20.29	0.205	15.78	104.47	0.880
Time [T1 Vs T0]	-8.63	4.51	0.063	-5.38	3.65	0.152	-21.81	13.82	0.118
Time [T2 Vs T0]	-13.39	5.11	0.010	-10.31	4.46	0.026	-28.46	18.82	0.132
Group [NLP Vs Control]	0.73	4.00	0.855	-0.23	3.42	0.946	-4.08	15.39	0.791
Group [LP Vs Control]	3.47	4.74	0.468	2.90	3.35	0.389	20.37	15.36	0.186
Decimal Age	9.52	3.97	0.018	6.69	3.43	0.058	14.95	16.10	0.354
Sex	-10.12	3.42	0.006	-6.91	2.21	0.003	-36.94	12.47	0.004
IOTF SDS BMI	-0.90	1.05	0.396	-1.20	0.81	0.149	-6.11	3.66	0.099
Special educational needs	-4.41	4.27	0.304	-3.30	3.13	0.294	-20.11	17.64	0.256
Index of multiple deprivation	0.14	0.85	0.869	-0.17	0.58	0.767	3.43	3.36	0.309
Ethnicity code	7.29	2.86	0.013	8.15	2.17	<0.001	47.87	10.93	<0.001
Sport events	-4.56	5.44	0.404	-2.71	4.34	0.535	-18.43	18.21	0.314
Mean rainfall (mm rain)	-0.79	0.43	0.080	-0.73	0.33	0.038	-2.80	1.28	0.034
Mean Temperature (Celsius degrees)	0.40	0.38	0.298	0.29	0.31	0.350	0.77	1.22	0.529
Daylight (% of day duration)	0.51	0.17	0.006	0.34	0.14	0.030	1.00	0.48	0.044
Valid wear time	3.12	0.65	<0.001	1.86	0.44	<0.001	3.23	1.99	0.108
Time [T1] * Group [NLP] Vs Control	-2.50	4.68	0.595	-0.75	4.26	0.861	7.55	14.69	0.608
Time [T2] * Group [NLP] Vs Control	1.67	5.39	0.758	2.74	4.16	0.515	7.61	14.86	0.610
Time [T1] * Group [LP] Vs Control	0.64	4.88	0.897	-0.81	4.02	0.841	4.76	18.96	0.803
Time [T2] * Group [LP] Vs Control	-3.91	4.87	0.426	-1.74	4.18	0.680	-13.69	14.70	0.355
Random Effects									
$\sigma 2$	399.93			228.19			4254.6		
$\tau 00$ Children	323.41			174.87			7163.9		
Intraclass correlation coefficient	0.45			0.43			0.6		
Number of children	360			360			360		
Observations	1080			1080			1080		
Marginal R2 / Conditional R2	0.17/0.54			0.18/0.53			0.11/0.67		

MVPA: Moderate to vigorous physical activity; **ENMO**: Euclidean norm minus one; **M60:** minimum acceleration in the most active hour; **Std. error:** standard error; **T0:** Baseline; **T1:** Post Intervention **T2:** Follow-up; **NLP:** Nonlinear Pedagogy group; **LP:** Linear Pedagogy group; **IOTF SDS BMI:** International Obesity Task Force standardised Body Mass Index, **$\sigma 2$:** Intercept variance; **$\tau 00$:** Random factor variance

In school physical activity

Predictors	MVPA Estimate	Std. error	p-value	Mean ENMO estimate	Std. error	p-value	M30 Estimate	Std error	p-value
(Intercept)	16.46	11.88	0.172	73.88	29.84	0.018	263.559	121.715	0.035
Time [T1 Vs T0]	-1.38	1.60	0.396	-6.05	4.25	0.166	-12.287	14.541	0.402
Time [T2 Vs T0]	-3.36	1.73	0.053	-4.06	4.58	0.379	-12.443	19.191	0.519
Group [NLP Vs Control]	-0.18	2.25	0.936	-2.32	5.51	0.674	-18.288	22.233	0.411
Group [LP Vs Control]	-2.38	2.23	0.288	-8.91	5.60	0.112	-45.447	22.58	0.045
Decimal Age	2.18	1.48	0.142	2.09	4.00	0.605	10.73	16.713	0.523
Sex	-7.29	1.06	<0.001	-20.28	2.55	<0.001	-92.133	11.246	<0.001
IOTF SDS BMI	-0.13	0.41	0.756	-1.24	0.75	0.098	-5.933	3.367	0.081
Special educational needs	2.00	1.67	0.235	4.01	3.92	0.308	1.874	18.093	0.918
Index of multiple deprivation	-0.16	0.32	0.631	-1.09	0.77	0.159	-3.377	3.199	0.292
Ethnicity code	-0.86	1.28	0.506	0.52	2.53	0.837	-6.843	12.833	0.595
Sport events	4.95	2.30	0.039	15.23	5.38	0.007	61.307	19.901	0.003
Mean rainfall (mm rain)	-0.34	0.15	0.022	-1.08	0.46	0.024	-1.045	1.61	0.519
Mean Temperature (Celsius degrees)	0.22	0.14	0.114	1.00	0.31	0.002	4.839	1.405	0.002
Daylight (% of day duration)	0.12	0.06	0.071	0.25	0.15	0.097	-0.074	0.569	0.897
Valid wear time	0.90	1.07	0.411	1.40	2.51	0.582	4.623	10.613	0.666
Time [T1] * Group [NLP] Vs Control	-1.56	1.55	0.318	-3.29	3.57	0.358	-14.936	13.151	0.257
Time [T2] * Group [NLP] Vs Control	2.23	1.57	0.162	1.45	5.19	0.783	-3.185	15.374	0.837
Time [T1] * Group [LP] Vs Control	0.81	2.27	0.724	0.71	5.02	0.887	-5.437	18.36	0.768
Time [T2] * Group [LP] Vs Control	0.39	1.48	0.792	2.62	3.72	0.482	2.341	14.128	0.869
Random Effects									
σ2	43.63			284.84			4148.77		
τ00 Children	51.02			267.33			6073.31		
τ00 Class	7.40			48.88			841.46		
Intraclass correlation coefficient	0.57			0.65			0.63		
Number of children	360			360			360		
N classes	18			18			18		
Observations	1080			1080			1080		
Marginal R2 / Conditional R2	0.23/0.67			0.27/0.65			0.23/0.71		

MVPA: Moderate to vigorous physical activity; **ENMO**: Euclidean norm minus one; **M30:** minimum acceleration in the most active half hour; **Std. error:** standard error; **T0:** Baseline; **T1:** Post Intervention **T2:** Follow-up; **NLP:** Nonlinear Pedagogy group; **LP:** Linear Pedagogy group; **IOTF SDS BMI:** International Obesity Task Force standardised Body Mass Index, **σ2:** Intercept variance; **τ00:** Random factor variance

Out of school physical activity from 15:00 to 23:00

	MVPA			Mean ENMO			M30		
Predictors	**Estimate**	**Std. error**	**p-value**	**estimate**	**Std. error**	**p-value**	**Estimate**	**Std error**	**p-value**
(Intercept)	-18.90	11.54	0.103	-14.94	25.46	0.562	-71.88	78.12	0.358
Time [T1 Vs T0]	-0.41	2.26	0.858	-0.70	3.36	0.836	4.82	14.82	0.748
Time [T2 Vs T0]	-1.58	2.42	0.516	-3.27	4.03	0.420	6.96	16.13	0.667
Group [NLP Vs Control]	2.01	2.03	0.324	2.16	3.21	0.503	0.35	12.82	0.978
Group [LP Vs Control]	4.19	2.17	0.058	5.90	3.18	0.066	8.28	12.63	0.513
Decimal Age	2.83	1.90	0.140	4.10	3.40	0.233	14.14	12.19	0.248
Sex	-3.03	1.29	0.021	-5.92	1.87	0.002	-37.50	7.92	<0.001
IOTF SDS BMI	-0.40	0.42	0.342	-0.69	0.92	0.459	-4.16	3.32	0.218
Special educational needs	-4.11	2.12	0.057	-6.38	2.93	0.031	-27.87	13.75	0.046
Index of multiple deprivation	-0.05	0.34	0.882	-0.06	0.65	0.930	0.66	2.52	0.794
Ethnicity code	2.19	1.54	0.164	5.14	2.43	0.042	28.25	10.04	0.008
Sport events	1.87	2.49	0.454	2.78	4.93	0.577	18.55	15.62	0.237
Mean rainfall (mm rain)	-0.53	0.22	0.017	-0.74	0.38	0.058	-1.48	1.56	0.351
Mean Temperature (Celsius degrees)	-0.13	0.19	0.502	-0.21	0.26	0.439	0.15	1.31	0.912
Daylight (% of day duration)	0.35	0.08	<0.001	0.52	0.14	0.001	2.38	0.55	<0.001
Valid wear time	1.89	0.42	<0.001	2.61	0.79	0.002	6.52	2.87	0.029
Time [T1] * Group [NLP] Vs Control	-2.09	2.11	0.326	-1.58	3.20	0.623	3.24	13.46	0.811
Time [T2] * Group [NLP] Vs Control	-0.28	2.27	0.902	0.49	3.83	0.899	10.71	13.04	0.413
Time [T1] * Group [LP] Vs Control	-4.17	2.69	0.126	-5.84	4.78	0.228	-15.90	16.16	0.327
Time [T2] * Group [LP] Vs Control	-3.89	2.19	0.079	-4.30	3.73	0.253	0.11	12.67	0.993
Random Effects									
σ2	92.42			243.02			3437.31		
τ00 Children	69.58			165.69			3357.13		
Intraclass correlation coefficient	0.43			0.41			0.50		
Number of children	360			360			360		
Observations	1080			1080			1080		
Marginal R2 / Conditional R2	0.16/0.52			0.15/0.50			0.23/0.61		

MVPA: Moderate to vigorous physical activity; **ENMO**: Euclidean norm minus one; **M30:** minimum acceleration in the most active half hour; **Std. error:** standard error; **T0:** Baseline; **T1:** Post Intervention **T2:** Follow-up; **NLP:** Nonlinear Pedagogy group; **LP:** Linear Pedagogy group; **IOTF SDS BMI:** International Obesity Task Force standardised Body Mass Index, **σ2:** Intercept variance; **τ00:** Random factor variance

Supplementary material 12. Complete cases analysis results in study 4

Whole week physical activity

	MVPA			Mean ENMO			M60		
Predictors	**Estimate**	**Std. error**	**p-value**	**estimate**	**Std. error**	**p-value**	**Estimate**	**Std. error**	**p-value**
(Intercept)	-56.23	23.95	0.019	-19.91	17.97	0.268	51.58	88.71	0.561
Time [T1 Vs T0]	-12.71	11.66	0.276	-5.78	9.00	0.521	-55.25	43.83	0.207
Time [T2 Vs T0]	-15.98	4.91	0.001	-10.75	3.74	0.004	-21.11	18.34	0.25
Group [NLP Vs Control]	1.19	3.40	0.726	0.28	2.59	0.915	-15.45	12.68	0.223
Group [LP Vs CG]	2.65	3.32	0.425	1.77	2.53	0.483	0.96	12.39	0.938
Decimal Age	10.50	3.42	0.002	7.10	2.54	0.005	16.64	12.60	0.187
Sex	-11.93	2.05	<0.001	-10.24	1.52	<0.001	-60.77	7.54	<0.001
IOTF SDS BMI	-0.80	0.68	0.242	-1.01	0.51	0.05	-6.35	2.54	0.012
Special educational needs	-4.51	3.21	0.16	-3.12	2.39	0.192	-20.37	11.83	0.085
Index of multiple deprivation	-0.13	0.61	0.827	-0.34	0.45	0.449	-0.22	2.24	0.92
Ethnicity code	2.03	2.06	0.324	3.70	1.53	0.015	22.60	7.58	0.003
Sport events	4.15	4.69	0.377	3.94	3.66	0.281	19.58	17.72	0.269
Mean rainfall (mm rain)	-0.77	0.43	0.073	-0.52	0.33	0.116	-3.83	1.61	0.017
Mean Temperature (Celsius degrees)	0.37	0.45	0.415	0.25	0.35	0.477	2.36	1.69	0.162
Daylight (% of day duration)	0.62	0.23	0.008	0.39	0.18	0.028	1.79	0.87	0.039
Valid wear time	2.79	0.67	<0.001	1.77	0.52	0.001	1.85	2.52	0.462
Time [T1] * Group [NLP] Vs Control	-2.02	3.71	0.587	-0.32	2.90	0.913	0.28	14.03	0.984
Time [T2] * Group [NLP] Vs Control	5.73	4.35	0.188	4.52	3.40	0.183	3.12	16.44	0.849
Time [T1] * Group [LP] Vs Control	-1.63	4.94	0.742	-1.65	3.86	0.668	-6.98	18.67	0.708
Time [T2] * Group [LP] Vs Control	-1.22	4.04	0.762	-0.80	3.16	0.799	-10.63	15.28	0.487
Random Effects									
σ2	156.34			97.2			2254.68		
τ00 Children	180.15			93.44			2376.08		
Intraclass correlation coefficient	0.54			0.49			0.51		
Number of children	274			274			274		
Observations	575			575			575		
Marginal R2 / Conditional R2	0.31/0.68			0.34/0.66			0.29/0.65		

MVPA: Moderate to vigorous physical activity; **ENMO**: Euclidean norm minus one; **M60:** minimum acceleration in the most active hour; **Std. error:** standard error; **T0:** Baseline; **T1:** Post Intervention **T2:** Follow-up; **NLP:** Nonlinear Pedagogy group; **LP:** Linear Pedagogy group; **IOTF SDS BMI:** International Obesity Task Force standardised Body Mass Index, **σ2:** Intercept variance; **τ00:** Random factor variance

Weekend physical activity

	MVPA			Mean ENMO			M60		
Predictors	**Estimate**	**Std. error**	**p-value**	**estimate**	**Std. error**	**p-value**	**Estimate**	**Std error**	**p-value**
(Intercept)	-108.11	30.73	<0.001	-66.22	22.79	0.004	-172.44	121.64	0.156
Time [T1 Vs T0]	-32.50	15.81	0.04	-22.38	11.86	0.059	-142.88	62.54	0.022
Time [T2 Vs T0]	-29.06	6.89	<0.001	-22.31	5.16	<0.001	-87.39	27.26	0.001
Group [NLP Vs Control]	0.33	4.77	0.945	-0.34	3.57	0.924	-6.60	18.89	0.727
Group [LP Vs Control]	6.66	4.72	0.158	5.19	3.53	0.142	28.66	18.69	0.125
Decimal Age	14.87	4.44	0.001	11.40	3.28	0.001	30.78	17.59	0.08
Sex	-10.15	2.66	<0.001	-7.35	1.97	<0.001	-37.05	10.54	<0.001
IOTF SDS BMI	-1.13	0.93	0.224	-1.32	0.69	0.057	-7.48	3.69	0.043
Special educational needs	-7.11	4.21	0.092	-5.08	3.12	0.103	-28.74	16.69	0.085
Index of multiple deprivation	0.11	0.79	0.888	-0.19	0.58	0.748	0.36	3.12	0.908
Ethnicity code	6.02	2.68	0.025	7.47	1.98	<0.001	52.29	10.62	<0.001
Sport events	-9.44	7.04	0.18	-7.38	5.32	0.165	-51.98	27.84	0.062
Mean rainfall (mm rain)	-1.12	0.45	0.012	-0.79	0.34	0.02	-4.27	1.77	0.016
Mean Temperature (Celsius degrees)	1.08	0.56	0.052	0.79	0.42	0.06	4.23	2.21	0.055
Daylight (% of day duration)	0.86	0.34	0.012	0.57	0.26	0.026	3.02	1.35	0.026
Valid wear time	3.23	0.68	<0.001	1.99	0.51	<0.001	4.15	2.68	0.122
Time [T1] * Group [NLP] Vs Control	-1.18	5.86	0.841	1.97	4.44	0.656	19.29	23.17	0.405
Time [T2] * Group [NLP] Vs Control	9.41	6.57	0.152	8.71	4.97	0.08	33.42	25.96	0.198
Time [T1] * Group [LP] Vs Control	0.88	7.40	0.905	-0.28	5.60	0.959	12.70	29.26	0.664
Time [T2] * Group [LP] Vs Control	-0.88	5.87	0.881	-0.91	4.44	0.838	-2.41	23.19	0.917
Random Effects									
σ2	403.96			233.58			6310.18		
τ00 Children	234.45			121.24			3685.88		
Intraclass correlation coefficient	0.37			0.34			0.37		
Number of children	274			274			274		
Observations	575			575			575		
Marginal R2 / Conditional R2	0.23/0.51			0.24/0.50			0.17/0.48		

MVPA: Moderate to vigorous physical activity; **ENMO**: Euclidean norm minus one; **M60:** minimum acceleration in the most active hour; **Std. error:** standard error; **T0:** Baseline; **T1:** Post Intervention **T2:** Follow-up; **NLP:** Nonlinear Pedagogy group; **LP:** Linear Pedagogy group; **IOTF SDS BMI:** International Obesity Task Force standardised Body Mass Index, **σ2:** Intercept variance; **τ00:** Random factor variance

In school physical activity

Predictors	MVPA Estimate	Std. error	p-value	Mean ENMO estimate	Std. error	p-value	M30 Estimate	Std error	p-value
(Intercept)	10.99	15.53	0.479	28.90	38.50	0.453	51.86	167.19	0.756
Time [T1 Vs T0]	8.29	5.62	0.14	16.69	14.44	0.248	-12.33	64.07	0.847
Time [T2 Vs T0]	-5.59	2.42	0.021	-9.32	6.05	0.123	-3.78	26.42	0.886
Group [NLP Vs Control]	-2.35	2.80	0.403	-5.96	6.81	0.381	-20.90	29.41	0.477
Group [LP Vs Control]	-5.37	2.84	0.059	-12.25	6.90	0.076	-51.34	29.81	0.085
Decimal Age	2.85	1.66	0.086	5.96	3.98	0.134	19.71	16.93	0.244
Sex	-7.47	0.98	<0.001	-20.54	2.36	<0.001	-94.09	10.04	<0.001
IOTF SDS BMI	-0.07	0.33	0.844	-0.78	0.81	0.333	-4.56	3.49	0.191
Special educational needs	0.43	1.58	0.783	2.12	3.81	0.577	3.13	16.24	0.847
Index of multiple deprivation	0.01	0.30	0.975	-0.61	0.72	0.391	-1.47	3.05	0.629
Ethnicity code	-0.34	1.11	0.757	1.77	2.66	0.506	2.39	11.33	0.833
Sport events	7.55	2.41	0.002	21.51	6.26	0.001	91.51	27.93	0.001
Mean rainfall (mm rain)	-0.07	0.22	0.733	-0.63	0.56	0.262	-4.47	2.48	0.071
Mean Temperature (Celsius degrees)	0.04	0.20	0.835	0.51	0.52	0.331	5.71	2.33	0.014
Daylight (% of day duration)	-0.12	0.12	0.327	-0.26	0.31	0.398	-0.55	1.37	0.686
Valid wear time	2.91	1.89	0.124	8.62	4.77	0.071	34.30	20.96	0.102
Time [T1] * Group [NLP] Vs Control	0.16	1.78	0.93	-0.86	4.61	0.852	-14.68	20.57	0.475
Time [T2] * Group [NLP] Vs Control	5.18	2.11	0.014	7.42	5.46	0.174	-25.53	24.34	0.294
Time [T1] * Group [LP] Vs Control	1.98	2.56	0.439	1.33	6.64	0.841	-4.73	29.59	0.873
Time [T2] * Group [LP] Vs Control	2.34	2.01	0.244	5.08	5.20	0.329	-6.74	23.19	0.771
Random Effects									
σ2	38.99			267.81			5393.32		
τ00 Children	38.22			198.8			3337.95		
τ00 Class	15.49			88.34			1628.16		
Intraclass correlation coefficient	0.58			0.52			0.48		
Number of children	274			274			274		
N classes	18			18			18		
Observations	575			575			575		
Marginal R2 / Conditional R2	0.29/0.70			0.33/0.68			0.30/0.63		

MVPA: Moderate to vigorous physical activity; **ENMO**: Euclidean norm minus one; **M30:** minimum acceleration in the most active half hour; **Std. error:** standard error; **T0:** Baseline; **T1:** Post Intervention **T2:** Follow-up; **NLP:** Nonlinear Pedagogy group; **LP:** Linear Pedagogy group; **IOTF SDS BMI:** International Obesity Task Force standardised Body Mass Index, **σ2:** Intercept variance; **τ00:** Random factor variance

Out of school physical activity from 15:00 to 23:00

	MVPA			Mean ENMO			M30		
Predictors	**Estimate**	**Std. error**	**p-value**	**estimate**	**Std. error**	**p-value**	**Estimate**	**Std error**	**p-value**
(Intercept)	-31.69	14.94	0.034	-30.84	23.75	0.194	-180.01	97.86	0.066
Time [T1 Vs T0]	-1.65	7.68	0.830	0.05	12.18	0.997	-38.47	50.87	0.450
Time [T2 Vs T0]	-3.83	3.34	0.251	-4.10	5.30	0.439	29.67	22.01	0.178
Group [NLP Vs Control]	2.56	2.30	0.266	4.59	3.66	0.210	13.41	15.19	0.377
Group [LP Vs Control]	4.85	2.26	0.032	8.45	3.59	0.019	30.66	14.90	0.040
Decimal Age	4.76	2.23	0.033	6.47	3.55	0.068	17.62	14.57	0.226
Sex	-3.00	1.33	0.024	-5.67	2.12	0.008	-42.02	8.71	<0.001
IOTF SDS BMI	-0.22	0.46	0.635	-0.57	0.74	0.435	-4.79	3.04	0.115
Special educational needs	-4.51	2.11	0.032	-7.12	3.35	0.034	-31.83	13.77	0.021
Index of multiple deprivation	-0.11	0.40	0.781	-0.26	0.63	0.679	1.01	2.59	0.697
Ethnicity code	1.03	1.34	0.445	3.51	2.14	0.100	27.66	8.77	0.002
Sport events	5.20	3.44	0.131	8.40	5.46	0.124	31.02	22.87	0.175
Mean rainfall (mm rain)	-0.44	0.29	0.135	-0.68	0.47	0.143	-3.36	1.95	0.085
Mean Temperature (Celsius degrees)	-0.20	0.29	0.480	-0.50	0.45	0.272	-0.03	1.90	0.987
Daylight (% of day duration)	0.41	0.16	0.010	0.64	0.25	0.011	4.26	1.06	<0.001
Valid wear time	1.81	0.47	<0.001	2.39	0.75	0.001	7.40	3.13	0.018
Time [T1] * Group [NLP] Vs Control	-2.61	2.64	0.323	-3.37	4.19	0.421	-4.48	17.59	0.799
Time [T2] * Group [NLP] Vs Control	0.61	3.07	0.844	0.52	4.87	0.916	6.64	20.43	0.745
Time [T1] * Group [LP] Vs Control	-7.74	3.71	0.037	-12.24	5.89	0.038	-48.03	24.70	0.052
Time [T2] * Group [LP] Vs Control	-4.41	2.94	0.134	-7.44	4.66	0.111	-23.25	19.58	0.235
Random Effects									
σ2	90.96			228.21			4057.75		
τ00 Children	64.3			163.66			2652.47		
Intraclass correlation coefficient	0.41			0.42			0.4		
Number of children	274			274			274		
Observations	575			575			575		
Marginal R2 / Conditional R2	0.18/0.52			0.17/0.52			0.32/0.59		

MVPA: Moderate to vigorous physical activity; **ENMO**: Euclidean norm minus one; **M30:** minimum acceleration in the most active half hour; **Std. error:** standard error;**T0:** Baseline; **T1:** Post Intervention **T2:** Follow-up; **NLP:** Nonlinear Pedagogy group; **LP:** Linear Pedagogy group; **IOTF SDS BMI:** International Obesity Task Force standardised Body Mass Index, **σ2:** Intercept variance; **τ00:** Random factor variance