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DANIEL KREUGER DE AGUIAR

O DESENVOLVIMENTO MOTOR NA PRÉ-ESCOLA: relações entre aptidão física, cognição e fatores ambientais

Rio de Janeiro, 2022

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O DESENVOLVIMENTO MOTOR NA PRÉ-ESCOLA: relações entre aptidão física, cognição e fatores ambientais

Tese de doutorado apresentada ao Programa de Pós-Graduação em Educação, como requisito parcial para a obtenção do título de Doutor em Educação pela Universidade Federal do Rio de Janeiro.

Orientador: Tiago Lisboa Bartholo

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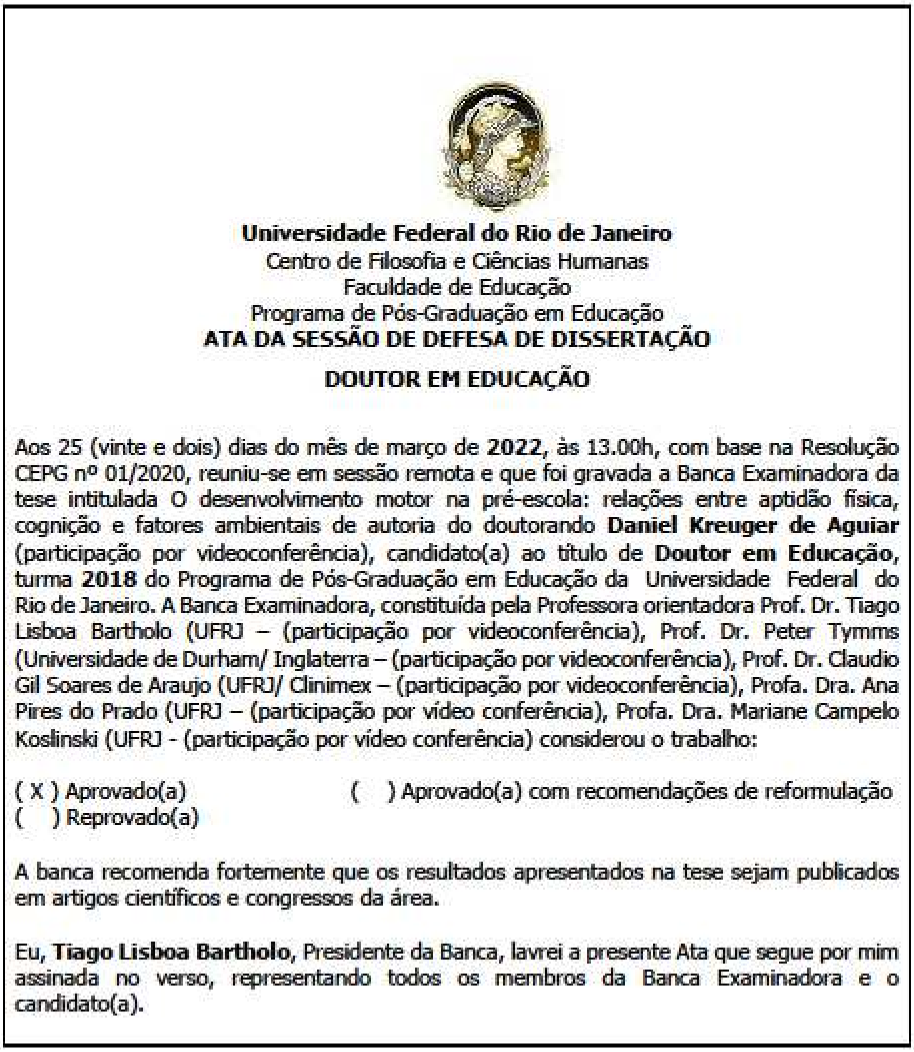

Universidade Federal do Rio de Janeiro
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ATA DA SESSÃO DE DEFESA DE DISSERTAÇÃO

DOUTOR EM EDUCAÇÃO

Aos 25 (vinte e dois) dias do mês de março de **2022**, às 13.00h, com base na Resolução CEPG nº 01/2020, reuniu-se em sessão remota e que foi gravada a Banca Examinadora da tese intitulada O desenvolvimento motor na pré-escola: relações entre aptidão física, cognição e fatores ambientais de autoria do doutorando **Daniel Kreuger de Aguiar** (participação por videoconferência), candidato(a) ao título de **Doutor em Educação**, turma **2018** do Programa de Pós-Graduação em Educação da Universidade Federal do Rio de Janeiro. A Banca Examinadora, constituída pela Professora orientadora Prof. Dr. Tiago Lisboa Bartholo (UFRJ – (participação por videoconferência), Prof. Dr. Peter Tymms (Universidade de Durham/ Inglaterra – (participação por videoconferência), Prof. Dr. Claudio Gil Soares de Araujo (UFRJ/ Clinimex – (participação por videoconferência), Profa. Dra. Ana Pires do Prado (UFRJ – (participação por vídeo conferência), Profa. Dra. Mariane Campelo Koslinski (UFRJ - (participação por vídeo conferência) considerou o trabalho:

(X) Aprovado(a) ( ) Aprovado(a) com recomendações de reformulação
( ) Reprovado(a)

A banca recomenda fortemente que os resultados apresentados na tese sejam publicados em artigos científicos e congressos da área.

Eu, **Tiago Lisboa Bartholo**, Presidente da Banca, lavrei a presente Ata que segue por mim assinada no verso, representando todos os membros da Banca Examinadora e o candidato(a).

Continuação da Ata de Defesa de tese do doutorando **Daniel Kreuger de Aguiar,** realizada em 22 de outubro de 2021.

Prof. Dr. Tiago Lisboa Bartholo (UFRJ)
Profa. Dra. Ana Pires do Prado (UFRJ)
Prof.a Dr.a Mariane Campelo Koslinski (UFRJ)
Prof.Dr. Claudio Gil Soares de Araujo (UFRJ/ Clinimex)
Prof.Dr. Peter B. Tymms (Universidade de Durham/ Inglaterra)

Daniel Kreuger de Aguiar – candidato

Tiago Lisboa Bartholo (UFRJ)
Presidente da Banca

SUMMARY

AGRADECIMENTOS

Esta tese é de autoria individual, porém é fruto de um trabalho de imensa dedicação coletiva. Todos e todas que participaram tiveram um papel importante, independentemente do tamanho da contribuição.

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ABBREVIATIONS AND ACRONYMS

ADHD – Attention Deficit Hyperactivity Disorder

BDNF – Brain-derived neurotrophic factor

BNCC – *Base Nacional Curricular Comum* / Brazil's National Curriculum

CEB - *Câmara de Educação Básica* (Basic Education Chamber)

CNE – *Conselho Nacional de Educação* / National Council of Education

CSDH – Commission on Social Determinants of Health

ECE – Early Childhood Education

EDI – *Espaço de Desenvolvimento Infantil* / Child Development Center

ES – Effect size

HLM – Hierarchical Linear Model

ICC – Intra class correlation

IGF-1 – Insulin-like growth factor 1

IMD – Indices of Multiples Deprivation

LAPOPE – Laboratório de Pesquisa em oportunidades educacionais / Educational Opportunities Research Laboratory

MABC-2 – Movement Assessment Battery for Children Second Edition

PI – Ponderal index

PIPS – Performance Indicators for Primary Schools

PPV-IBGE – Pesquisa de Padrão de Vida do Instituto Brasileiro de Geografia e Estatística / Life Standard Survey of the Brazilian Institute of Geography and Statistics

RCT – Random controlled trial

SAEB – *Sistema de Avaliação da Educação Básica* / Basic Education Assessment System

SDQ – Strengths and Difficulties Questionnaire

SEN – Special educational needs

SES – Socioeconomic status

SRT – Sitting-Rising Test

UFRJ – *Universidade Federal do Rio de Janeiro* / Federal University of Rio de Janeiro

UNESCO – United Nations Educational, Scientific and Cultural Organization

RESUMO

AGUIAR, Daniel Kreuger de. **O desenvolvimento motor na pré-escola: relações entre aptidão física, cognição e fatores ambientais**. Rio de Janeiro, 2022. Tese (Doutorado em Educação) – Faculdade de Educação, Universidade Federal do Rio de Janeiro, Rio de Janeiro, 2022.

Esta tese tem como objetivo compreender como a dimensão motora do desenvolvimento infantil se relaciona com fatores ambientais, cognição e participação na pré-escola em crianças de 4 e 5 anos. As análises utilizaram dados de um estudo longitudinal de larga escala realizado no Rio de Janeiro entre 2017 e 2018 com uma amostra probabilística da rede pública de ensino. Esta tese tem três objetivos específicos: i) analisar a relação entre o nível socioeconômico das famílias e a aptidão física não-aeróbica das crianças, ii) analisar a relação entre a aptidão física não-aeróbica e o desenvolvimento cognitivo durante os dois primeiros anos de escolaridade obrigatória e, iii) investigar o impacto da pré-escola no desenvolvimento da aptidão física não-aeróbica das crianças. A aptidão física não-aeróbica foi avaliada através do Teste Sentar e Levantar (TSL) (ARAÚJO, 1999). O desenvolvimento cognitivo foi avaliado através do desempenho em linguagem e matemática usando a versão adaptada do *Performance Indicator for Primary Schools* (PIPS). O nível socioeconômico das famílias (NSE) foi medido por meio de um questionário que continha diversas informações contextuais. A amostra incluiu 2.186 e 2.315 crianças com duas medidas longitudinais do TSL e PIPS no primeiro e segundo ano da pré-escola, respectivamente. Análises por meio de Modelos Lineares Hierárquicos estimaram fatores contextuais relacionados à aptidão física não-aeróbica e a relação entre aptidão física não-aeróbica e desenvolvimento cognitivo. Além disso, análises utilizando um desenho quase-experimental que considerou a alocação das unidades plausivelmente “como se fosse” aleatória (DUNNING, 2008) investigou o impacto da pré-escola no desenvolvimento da aptidão física não-aeróbica. Os resultados sugerem que: i) NSE e aptidão física não-aeróbica das crianças não apresentaram associação significativa na amostra do estudo ($p \geq 0,05$); ii) existe uma associação longitudinal positiva entre as medidas iniciais do TSL e desempenho em matemática após controlar por fatores contextuais, demográficos e medidas cognitivas iniciais ($p < 0,05$). Além disso, as análises que consideraram a relação entre as mudanças nas medidas do TSL e o desenvolvimento cognitivo futuro durante o primeiro e segundo ano da pré-escola indicaram resultados na mesma direção ($p < 0,05$); iii) frequentar a pré-escola impacta positivamente a aptidão física não-aeróbica das crianças no primeiro ano da escolaridade obrigatória ($p < 0,05$). Particularmente, esse efeito positivo foi maior para crianças de famílias com baixo nível socioeconômico. As implicações para as políticas educacionais na educação infantil são discutidas no estudo, juntamente com recomendações para pesquisas futuras.

Palavras-chave: Desenvolvimento motor; Aptidão física; Cognição; Educação infantil; Efeito escola; Fatores ambientais.

ABSTRACT

AGUIAR, Daniel Kreuger de. **O desenvolvimento motor na pré-escola: relações entre aptidão física, cognição e fatores ambientais**. Rio de Janeiro, 2022. Thesis (Ph.D. in Education) – Faculdade de Educação, Universidade Federal do Rio de Janeiro, Rio de Janeiro, 2022.

This thesis aims to understand how the motor dimension of child development is related to environmental factors, cognition, and preschool attendance in children aged 4 and 5 years. The analyses used data from a large-scale longitudinal study conducted in Rio de Janeiro from 2017 to 2018 with a probabilistic sample of the public educational network. This thesis has three specific aims: i) to analyze the relationship between the socioeconomic status of the families and the non-aerobic physical fitness of children, ii) to analyze the relationship between non-aerobic physical fitness and cognitive development during the first years of compulsory education, and iii) to investigate the impact of preschool on the development of children's non-aerobic physical fitness. The non-aerobic physical fitness was assessed using the Sitting-Rising Test (SRT) (ARAÚJO, 1999). The cognitive development was assessed considering language and mathematics performance using an adapted version of the Performance Indicator for Primary Schools (PIPS). Families' socioeconomic status (SES) was measured using a questionnaire that comprised several contextual information. The sample included 2,186 and 2,315 children with two longitudinal SRT and PIPS measures in the first and second year of preschool, respectively. Analyses using Hierarchical Linear Models estimated contextual factors related to the non-aerobic physical fitness and the relationship between non-aerobic physical fitness and cognitive development. In addition, analyses using a quasi-experimental design that considered the treatment assignment plausibly "as if" random (DUNNING, 2008) investigated the preschool's impact on the development of non-aerobic physical fitness. The findings suggest that: i) SES and children's non-aerobic physical fitness showed no significant association in the study's sample ($p \geq 0.05$); ii) there is a positive longitudinal association between baseline SRT measures and mathematics scores after controlling for contextual and demographic factors and baseline cognitive measures ($p < 0.05$). Moreover, the analyses that considered the relationship between changes in SRT measures and future cognitive development during the first and second year of preschool indicated results in the same direction ($p < 0.05$); iii) attending preschool impacts children's non-aerobic physical fitness positively in the first year of compulsory education ($p < 0.05$). Notably, this positive effect was higher for children from families with low socioeconomic status. Implications for educational policies in early childhood education are discussed in the study, along with recommendations for future research.

Keywords: Motor development; Physical fitness; Cognition; Early childhood education; School's effect; Environmental factors.

1 INTRODUCTION

This thesis aims to understand how the motor dimension of child development is related to environmental factors, cognition, and preschool attendance in children aged 4 and 5 years. There are three main objectives in the study. The first analyzes the relationship between the socioeconomic status of families and the non-aerobic physical fitness of children. The second examines the relationship between non-aerobic physical fitness and cognitive development during Brazil's first two years of compulsory education. The third objective estimates the impact of attending preschool on the development of children's non-aerobic physical fitness. To this end, this thesis uses data from a large-scale longitudinal study conducted in one Brazilian municipality, which aims to identify the characteristics of preschools and pedagogical processes associated with children's development in three dimensions, namely, cognitive, physical/motor and socio-emotional (BARTHOLO et al., 2020b, 2020a; KOSLINSKI; BARTHOLO, 2019). Finally, this thesis makes two main contributions: academically, it strengthens the educational research by providing robust evidence in an underexplored age group; from the point of view of public policies, it proposes recommendations for the educational policy of Early Childhood Education.

Human development, commonly divided into the cognitive, socio-emotional, motor, and physical dimensions, is often studied independently; however, it is essential to consider the interrelated structure of its domains (PAYNE; ISAACS, 2011). Theoretical models of human development highlight the relationship of motor and cognitive dimensions in the first years of life (ERIKSON, 1965; GESELL, 1928; PIAGET, 1952) and emphasize the influence of the environmental context - family, school, housing district, and other higher systems – in development (BRONFENBRENNER, 1979; NEWELL, 1984).

Motor development refers to continuous changes in the movement of individuals and factors (individual - environment - task) related to these changes (HAYWOOD; GETCHELL, 2014). Thus, the analysis of motor development can explore aspects related to movement (crawling, walking, running, picking up and throwing objects) and underlying factors, such as age, sex, socioeconomic status, and physical fitness.

Physical fitness can be operationalized as a set of measurable health-related attributes and skills, including cardiorespiratory fitness (aerobic fitness), muscle strength, power and endurance, body composition, balance, flexibility, motor coordination and reaction time (AMERICAN COLLEGE OF SPORTS MEDICINE, 2017; CASPERSEN; POWELL; CHRISTENSON, 1985). This set of components can be divided into two dimensions: *aerobic fitness*, having as a component the individual's aerobic/cardiorespiratory condition; and *non-aerobic physical fitness*, which includes at least four components: muscle strength/power, balance, flexibility, and body composition (ARAÚJO, 2015). The components of non-aerobic physical fitness, also known as musculoskeletal fitness, can be considered the basis for performing fundamental motor skills tasks and have been associated with cognitive and academic performance in children and adolescents aged 4 to 18 years (AGUIAR; BARTHOLO, 2019; AGUIAR; BARTHOLO; TAVARES JR., 2019; DE BRUIJN et al., 2019; ESTEBAN-CORNEJO et al., 2014b; SCHMIDT et al., 2017; VAN DER FELS et al., 2014).

The widely documented benefits of regular physical activity for children's health include bone health, reduced cholesterol, arterial hypertension, and metabolic risk factors (JANSSEN; LEBLANC, 2010; PATE et al., 2019). In addition to this improvement in physical function, small to moderate associations have been observed between physical activity and childhood cognition (ÁLVAREZ-BUENO et al., 2017, 2020; SIBLEY; ETNIER, 2003). However, some evidence on the association between physical activity and academic performance has been ambiguous. Some research shows a negative association (ESTEBAN-CORNEJO et al., 2014a) and others suggest null effects (DWYER et al., 2001). These results may indicate a low sensitivity of some instruments to collect information about the amount of physical activity performed by children (RACHELE et al., 2012). Therefore, some studies suggest physical fitness as a more informative physical activity index when exploring the link to academic performance and cognition (CHU et al., 2019; HANSEN et al., 2014).

Although the interest in the relationship of motor and cognitive dimensions of children has grown since the 2000s, the literature on the benefits of physical activity and physical fitness for cognition has been mainly addressed with older children or adults (ST. LAURENT et al., 2021; STILLMAN et al., 2016). Nevertheless, some systematic reviews have investigated the relationship between physical fitness and cognition in children. For example, the review by Fedewa and Ahn (2011) investigated the associations between physical fitness components and cognition in children and adolescents (5 to 16 years old), pointing out small to moderate positive results: aerobic fitness (ES: 0.40); muscle strength (ES: 0.18) and combined measures of all components (total fitness; ES: 0.39) [1]. In this same review, age group analyzes indicated higher effects for children at younger ages (5-10 years; ES: 0.36). Similarly, Santana et al. (2017) pointed out strong evidence regarding the association between aerobic fitness and combined measures of physical fitness components with academic performance of children and adolescents in cross-sectional and longitudinal studies. On the other hand, the relationship between non-aerobic components (muscle strength and flexibility) with academic performance remains uncertain, with mixed results.

The review by Donnelly et al.(2016) indicated that aerobic fitness was consistently associated with academic performance in children aged 5-13 years in longitudinal studies. On the other hand, some components of non-aerobic physical fitness (such as muscle strength/power and flexibility) seem to present inconsistent evidence concerning their association with cognitive abilities (SANTANA et al., 2017; SCHMIDT et al., 2017; SMITH et al., 2014). Together with others (BIDZAN-BLUMA; LIPOWSKA, 2018; CHU et al., 2019; HAAPALA, 2013), these reviews pointed out the need for future studies with research designs that allow a higher degree of causal inference (Randomized Control Trials - RCTs or longitudinal studies). Most of the studies found in these reviews have a cross-sectional/correlational design. Still, many of the cross-sectional and longitudinal studies do not use relevant control variables, such as the socioeconomic status of families, which is a significant predictor of academic performance (COLEMAN et al., 1966) and also a moderator of the relationship between physical fitness and cognition (DONNELLY et al., 2016).

Furthermore, as this area of research presents many studies with a greater focus on the aerobic component of physical fitness (STILLMAN et al., 2016), there is a paucity of scientific data regarding the non-aerobic components and their relationship with cognitive development in preschool children (HOUWEN et al., 2017; KAO et al., 2017). Thus, a better understanding between cognition and aspects of motor development, such as non-aerobic physical fitness, may provide relevant evidence for elaborating specific educational policies for Early Childhood Education.

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[1] Although the authors (FEDEWA; AHN, 2011) reported small to moderate effect sizes, they can be considered moderate to high from an educational perspective. See Higgins et al. (2016) for detailed information.

A significant moment in child development is the beginning of schooling, which establishes the first steps towards more structured socialization separated from the family environment. In Brazil's education system, Early Childhood Education (*Educação Infantil*), the first stage of Basic Education, comprises the Nursery (*Creche*), attending children from zero to three years old. The Pre-school, with children aged between four and five years old, corresponds to the beginning of compulsory education. Broadly, Brazil's national curriculum (*Base Nacional Curricular Comum* - BNCC) sets out that Early Childhood Education aims to enhance children in all dimensions of their development (cognitive, socio-emotional and motor) (BRASIL, 2010a, 2017).

Another relevant aspect concerning early childhood education involves biological development at this stage of life. In early childhood, skills and learning occur more quickly and easily, in what is considered a moment of "windows of opportunity" or sensitive periods, in which experiences powerfully shape many aspects of our perceptual, cognitive and emotional capacities, occurring in limited moments in life (KNUDSEN, 2004; LENT; OLIVEIRA, 2018).

In modern societies, there is a growing perception of the importance of Early Childhood Education for children's development. Studies from developed countries have estimated the impact of attending a quality preschool and pointed out relevant results with short and long-term effects. For example, early participation in the schooling process contributes to learning and longer school trajectories with fewer failures - school retentions and dropouts (PEISNER-FEINBERG et al., 1999; SYLVA et al., 2010), in addition to reducing the crime rate and social costs in general (HECKMAN et al., 2010). Such findings are meaningful mainly because the children from the low socioeconomic status benefit from the most expressive results, suggesting that investing in Early Childhood Education is an effective strategy for reducing educational inequalities.

Studies in Brazil also show positive impacts of attending preschool on school results. Curi and Menezes-Filho (2009), using data from a large-scale survey (PPV – IBGE, 1996 - 1997) and on information from Brazil's National Exam (SAEB 2003), analyzed the relationship between participation in early childhood education and academic achievement. The results indicated a positive and significant relationship between enrolling in early childhood education and the mean years of schooling concluded, in addition to a slight improvement in performance on proficiency tests. Using data from the SAEB - 2005, a study found that children enrolled in preschool had higher Mathematics proficiency in the 5th grade than those who did not (PINTO; SANTOS; GUIMARÃES, 2016). Campos et al. (2011) estimated the impact of preschool attendance on children's reading and math skills (measured by a national exam - *Provinha Brasil*) in the 2nd grade. The results showed that the preschool group had higher academic performance compared with children who did not attend preschool. However, we should interpret the results with caution, given their correlational design and the use of cognitive proficiency tests that represent an aggregate of learning over time.

Early Childhood Education's main objective is to promote the global development of children. However, from the evidence presented earlier, the main focus of studies investigating preschool's impact is on the cognitive dimensions. Therefore, encouraging the development of motor aspects in childhood should be part of strategies to provide quality education (UNESCO, 2015).

Studies investigating the effects of school on non-cognitive dimensions such as health-related behaviors focused on observing the influence of school on smoking or substance use by adolescents (MURRAY; KIRYLUK; SWAN, 1984; WEST; SWEETING; LEYLAND, 2004). In addition, systematic reviews investigated the effects of physical activity programs implemented in the school environment (daycare centers and preschools) (VELDMAN; JONES; OKELY, 2016; ZENG et al., 2017). The authors indicated that most programs provided significant improvements in the motor performance of preschool children. However, the studies selected in the reviews present interventions characterized as an extension of the school routine (extracurricular activity) and do not reflect the effect of preschool as an educational policy.

As mentioned earlier, physical fitness is associated with several health outcomes (JANSSEN; LEBLANC, 2010), mental well-being (LIU; WU; MING, 2015; LUBANS et al., 2016) and cognitive performance (DONNELLY et al., 2016; FEDEWA; AHN, 2011; SANTANA et al., 2017). Thus, studies that identify possible impacts of the school on physical fitness have great relevance suggesting that the school provides an ideal environment for promoting policies focused on public health and educational outcomes.

The questions that will guide this thesis are the following: a) what is the relationship between the socioeconomic status of families and the non-aerobic physical fitness of children at the beginning of preschool? b) is there a longitudinal association between children's non-aerobic physical fitness and their language and mathematics skills in the first two years of school? c) How is the development of non-aerobic physical fitness associated with children's learning during preschool? d) what is the role of preschool in the development of non-aerobic physical fitness in children?

1.1 Outline of the thesis

This thesis consists of eight chapters, including this introduction. *Chapter 2* presents the literature review regarding i) the relationship between socioeconomic status and physical fitness, ii) the relationship between physical fitness, physical activity, and cognition, and iii) the effects of physical activity interventions on motor dimensions. *Chapter 3* describes the thesis' aims and hypothesis. *Chapter 4* summarizes the methods, sample of participants, study designs, and key variables used in the thesis.

Chapter 5 describes children's non-aerobic physical fitness over the two years of preschool and explores factors associated with children's non-aerobic physical fitness focusing on socioeconomic status. *Chapter 6* analyzes the relationship between children's non-aerobic physical fitness and cognitive development with two distinct approaches. The first uses baseline measures of non-aerobic physical fitness as a predictor of cognitive development. The second examines the relationship between changes in non-aerobic physical fitness and children's cognitive development. *Chapter 7* analyzes preschool attendance's effect on non-aerobic physical fitness in the first year of preschool.

Finally, *Chapter 8* summarizes the findings reported in the thesis and presents implications for educational policies and future research. Additionally, the *Appendix* section offers the supplementary materials of the thesis' analyses.

2 LITERATURE REVIEW

This section presents a review of studies based on the three main objectives of the thesis. The first part will address studies on the relationship between socioeconomic status and physical fitness in children and adolescents. The second part presents studies that investigated the relationship between components of physical fitness and dimensions related to the cognition of children and adolescents, with a particular focus on preschool children. Finally, the third part addresses studies regarding the effect of school on non-cognitive dimensions, specifically those related to motor dimensions.

It is worth mentioning that research involving the relationship between motor and cognitive dimensions uses different constructs and measurement instruments. For example, motor dimensions can be measured by observing developmental milestones (rudimentary motor skills), fundamental motor skills, physical fitness and its components and physical activity levels. Regarding the cognitive dimensions, measures comprise grade point average, academic performance measured through standardized tests, and executive functions tests.

2.1 Definitions

To bring clarity and conciseness to the text, we will present definitions of key terms used throughout this thesis. Terms related to motor dimensions like physical activity, exercise, and physical fitness are often used interchangeably, which is not always appropriate. Likewise, terms linked to cognitive dimensions like cognition, executive functions, academic performance are sometimes used as interchangeable concepts in the literature.

2.1.1 Physical activity, exercise, and physical fitness

Physical activity can be defined as “any bodily movement produced by the contraction of skeletal muscles that results in a substantial increase in energy expenditure” (AMERICAN COLLEGE OF SPORTS MEDICINE, 2017; CASPERSEN; POWELL; CHRISTENSON, 1985). In addition, it can promote social and environmental interactions, occur during free time, commuting, at work, and in household tasks (BRASIL, 2021).

Exercise it’s a subcategory of physical activity that is planned, structured, and repetitive and has the objective to improve and/or maintain one or more components of physical fitness (AMERICAN COLLEGE OF SPORTS MEDICINE, 2017; CASPERSEN; POWELL; CHRISTENSON, 1985). So, every physical exercise is a physical activity, but not every physical activity is a physical exercise. (BRASIL, 2021).

Physical fitness has been defined in several ways, but the generally accepted definition is “the ability to carry out daily tasks with vigor and alertness, without undue fatigue, and with ample energy to enjoy leisure-time pursuits and meet unforeseen emergencies” (PHYSICAL ACTIVITY GUIDELINES ADVISORY COMMITTEE, 2018). Unlike physical activity and exercise, which are related to the movements performed by the individual, physical fitness is a set of attributes that a person has. Physical fitness has a genetic determinant, but environmental factors can significantly influence it (GALLAHUE; OZMUN; GOODWAY, 2019; ORTEGA et al., 2008). Physical fitness can be operationalized as a multicomponent construct including cardiorespiratory (aerobic) fitness, muscular strength, power and endurance, body composition, flexibility, balance, agility, coordination and reaction time (AMERICAN COLLEGE OF SPORTS MEDICINE, 2017; CASPERSEN; POWELL; CHRISTENSON, 1985). This set of attributes can be divided into two dimensions[2]: the aerobic dimension (aerobic fitness), having as a component the individual's aerobic/cardiorespiratory condition; and the non-aerobic dimension (non-aerobic physical fitness), which include at least four components: muscle strength/power, balance, flexibility and body composition (ARAÚJO, 2015).

2.1.2 Cognition, executive functions, and academic performance

Cognition is a broad term and, as different research areas analyze it, it can be defined in different ways. For example, Neisser (1976) defines cognition in humans as "all the processes by which sensory information is transformed, reduced, elaborated, stored, retrieved and used" (p.4). We can also conceive cognition as mental actions aimed at knowledge of the world and the individual, being an equivalent of thought (LENT, 2010). However, for the interests of this thesis, more important than a precise definition

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[2] Physical fitness components can be grouped into two other dimensions: Health-related Physical Fitness (aerobic fitness; muscle strength/endurance; flexibility) and Skill-related Physical Fitness (agility; coordination; balance; muscle power; reaction time; speed) (AMERICAN COLLEGE OF SPORTS MEDICINE, 2017). However, the components are the same and are just grouped differently.

is the notion that we can approach cognition through its multiple processes. Some of these processes are the executive functions and the academic performance.

Executive functions (EF; or cognitive functions) is an umbrella term for a set of mental processes commonly divided into three fundamental EF: inhibitory control, working memory, and cognitive flexibility (DIAMOND, 2013; MIYAKE et al., 2000). Higher-order executive functions are built from these, such as reasoning, problem-solving, and planning processes (COLLINS; KOECHLIN, 2012; LUNT et al., 2012).

Inhibitory control involves resisting internal impulses or predispositions that keep us from a goal. By temporarily preventing impulsive responses, inhibition allows the individual to have time to choose the most socially appropriate response or to adjust according to their purposes (LENT; OLIVEIRA, 2018). *Working memory* is the ability to hold information in the mind while performing mental operations. In addition, it is required in processes where it is necessary to establish connections between facts (DIAMOND, 2013). Finally*, Cognitive flexibility* comprises changing perspectives or approaches to a problem and the ability to flexibly adjust to new demands, rules, or priorities (such as switching between tasks) (DIAMOND, 2013). Thus, EFs are very connected to school routines, proving crucial for children's academic performance throughout the school trajectory (BEST; MILLER; NAGLIERI, 2011; SHAUL; SCHWARTZ, 2014). Furthermore, EFs are critical for several lifelong outcomes such as better health indicators, better financial conditions, and less likelihood of committing crimes (MOFFITT et al., 2011).

Academic performance is one of the ways of measuring cognition in children, and it observes the extent to which a student has achieved his or her educational goals (DONNELLY et al., 2016). Measures of academic performance generally use the averages of school grades obtained in a particular subject (which may be influenced by the teacher's opinion and the child's behavior in the classroom) or even standardized test results. These commonly assess a wide range of language and mathematics skills. EF, like inhibitory control and working memory, can influence academic performance (DIAMOND, 2013) as well as one's socioeconomic status.

2.1.3 Socioeconomic status

Socioeconomic status (SES) is a variable that usually synthesizes contextual information about individuals and families concerning their income, occupation, and education, allowing for analyzing classes of similar individuals with these characteristics. In educational research, the debate on socioeconomic status is a central theme due to its strong correlation with different school results, indicated by ample empirical evidence in several countries worldwide since the mid-1960s and in Brazil (COLEMAN et al., 1966; KOSLINSKI; BARTHOLO, 2020; MORTIMORE et al., 1988; TAVARES JR., 2018).

SES can be considered a proxy for the child's developmental opportunities that the family can offer. For example, more favorable financial conditions can create conditions for consuming cultural goods and experiences or allow parents to devote more time to monitor their children's school life (SOARES, 2005). In addition, the SES is a significant factor related to health and well-being as it influences people's attitudes, experiences, and exposure to various health risk factors (HUURRE; ARO; RAHKONEN, 2003).

2.2 Socioeconomic status and physical fitness in children and adolescents

In the educational debate, information related to families' socioeconomic status is crucial in investigations on development, learning, and other school results. Research from the large-scale surveys that started the tradition of research on the school effect, conducted in the second half of the 20th century until today (COLEMAN et al., 1966; JENCKS et al., 1972; KOSLINSKI; BARTHOLO, 2019), point to a robust positive relationship between the SES of families and students school results. Concerning this, measurement of information that synthesizes the background of families is essential and can be collected in different ways: parent's educational level; possession of goods; consumption of comfort items; family income; participation in cash transfer programs.

Among several environmental and contextual factors, SES plays an essential role in people's lifestyles and is one of the strongest determinants of variations in health outcomes in virtually all societies (CSDH, 2008). Socioeconomic inequality has been considered the leading cause of differences in health levels in the population (LINK; PHELAN, 1995), with studies associating low SES with high rates of low birth weight and non-communicable diseases (PAMUK et al., 1998). The components of physical fitness are also considered powerful markers of health since youth, serving as protective factors against the risk of metabolic and cardiovascular diseases (JANSSEN; LEBLANC, 2010; ORTEGA et al., 2008).

A high SES can directly present a beneficial effect by providing individuals with more significant financial resources in addition to health-related knowledge. Indirectly and more broadly, a high SES can shape and affect people's behavior and lifestyle (ADLER; NEWMAN, 2002). For example, individuals with higher SES tend to have healthier behaviors such as consuming more fruits and vegetables (IRALA-ESTÉVEZ et al., 2000), being more physically active (WILSON et al., 2004) and smoking less (HUURRE; ARO; RAHKONEN, 2003).

Studies that investigated the relationship between physical fitness and SES in children and adolescents showed results that associated a low socioeconomic level with low levels of physical fitness. However, these results are not entirely consistent. Box 2.1 presents a summary of the studies presented in this section.

Box 2.1: Descriptive characteristics of studies investigating the relationship between physical fitness and SES

Author	Study design / Participant's characteristics / Location	Assessment of Physical Fitness	Assessment of SES	Analyses	Main Results
Jin, Jones-Smith, (2015)	Cross sectional. 1,617,400 children (11-15 y-old). United States of America	FITNESSGRAM protocol: Aerobic fitness (1-mile run); Abdominal strength (curl-ups); Upper body strength (push-ups, modified pull-ups, or flexed-arm hang); Body composition (BMI); Trunk extensor strength and flexibility (trunk lift); Flexibility (sit-and-reach or shoulder stretch). Students receive 1 point if their test result falls in the Healthy Fitness Zone. The total points from the 6 fitness areas are summed to provide the fitness score, ranging from 0 (least healthy) to 6 (most healthy).	SES (low income, a dichotomous variable) was indicated by the eligibility for the National School Lunch Program (NSLP), a free or reduced-price meal program.	Multiple linear regression models adjusted by age, sex, and race/ethnicity	Lower family income (vs higher) was associated with lower fitness score. Lower-income children had higher prevalence of obesity compared with higher-income children.
Wolfe, Lee, Laurson (2020)	Cross sectional. 1,576 children and adolescents (3-15 y-old). United States of America	Musculoskeletal fitness: handgrip strength; leg extension dynamometer (lower body strength); modified pull-up (upper body strength); plank test (core muscular endurance); Aerobic fitness: treadmill test. Body composition: body mass index (BMI). Physical activity: questionnaire	SES (family income: low, moderate, high) was indicated by the family-income-to-poverty ratio indicator (FIPR).	Logistic regression was used to estimate the odds of having low fitness by SES category controlling for race/ethnicity and physical activity	The odds of low MSF fitness were higher in the low and moderate SES groups compared to the children from high SES families. The moderate SES group had an odd of poor CRF higher than the high SES group as well. Children and adolescents from high SES families tend to have higher mean fitness and were less likely to have low/poor fitness.

Pávon et al (2010)	Cross sectional. 3,259 adolescents (13-16 y-old). 9 European countries	Lower body muscular fitness (standing long jump, the squat jump, the counter movement jump and the Abalakov jump tests); Upper-body muscular fitness (Handgrip strength and the bent arm hang test); Aerobic fitness (shuttle run test 20m). Speed/ agility (4x10m shuttle run test).	SES (low, medium, high) was indicated by The Family Affluence Scale (FAS) based on the possession of material conditions in the family which reflected family expenditure and consumption	One-way analyses of variance (one-way ANOVA) adjusted by age, height, total body fat and physical activity	Adolescents with high SES had significantly higher fitness levels than their peers of lower SES categories, except for speed-agility and handgrip in boys.
Freitas et al. (2007)	Longitudinal. 1493 children and adolescents (8-18 y-old). Portugal	Balance (flamingo test); Hand-eye coordination (plate tapping); flexibility (sit and reach); Lower body muscular fitness (standing long jump); Upper-body muscular fitness (Handgrip strength, flexed arm hang); trunk strength (sit ups); Speed/ agility (5x10m shuttle run test); Aerobic fitness (12-min run–walk)	SES (low, average, high) was indicated by a standardized questionnaire developed by the Portuguese Institute of Statistics based on 5 characteristics (parental occupation, education, income, housing, and residential area features)	ANCOVA was performed to test for differences in physical fitness tests between SES groups using height and body mass as covariates	Boys from low SES do better than boys from average or high SES in flexibility and aerobic fitness. There are also indications that boys from high SES perform better than low SES in trunk strength and speed/agility, and that girls from high SES present better scores in speed/agility.
Guedes et al. (2012)	Cross sectional. 2,849 children and adolescents (6-18 y-old). Brazil	FITNESSGRAM: Flexibility (sit and reach); trunk strength (curl-up); Trunk extensor strength and flexibility (trunk lift); Upper body strength (push-up); Aerobic fitness (progressive endurance run (PACER)	SES (A-highest through E-lowest) was indicated by an index called Brazil Criterion based on the educational level of the parents, housing conditions, possession of household items and cars, and number of domestic employees	Binary logistic regression (proportion of schoolchildren who met the Fitnessgram health standards) adjusted by gender, age.	Boys and younger schoolchildren presented a significantly higher chance of meeting healthy levels of physical fitness. Children from families of low SES presented higher chance of meeting the health standards than those from high SES families.

Otero et al (2017)	Cross sectional. 1,691 children and adolescents (8-17 y-old). Spain	Upper-body muscular fitness (Handgrip strength)	SES was indicated by area of residence (urban or rural), membership in health insurance schemes, social strata of neighborhood, parental education, parental employment status, family income, and type of family unit (single parent or both parents living together with the child)	Multinomial multiple logistic regression models adjusted by age and sex	Lower HG strength was associated with indicators of higher socioeconomic status, such as living in an urban area, residence in higher social strata neighborhoods, parent/guardian with secondary education or higher.
Sandercock et al. (2017)	Cross sectional. 52,187 children (14-16 y-old). Colombia	Lower body muscular fitness (Standing long jump); Upper-body muscular fitness (Handgrip strength); Aerobic fitness (shuttle run test 20m). Body composition: body mass index (BMI)	Family income; Area-level SES	Hierarchical regression modeling adjusted by sex and body composition	Family income was not associated with muscular and aerobic fitness. Participants in the mid-SES and high-SES groups had better handgrip scores when adjusted for body composition.
Vermeiren et al (2018)	Cross sectional. 1403 children (4-12 y-old). Netherlands	Upper-body muscular fitness (Handgrip strength); Aerobic fitness (shuttle run test 20m). Body composition: body mass index (BMI)	SES (high-middle-low) was indicated by maternal education and parental material deprivation.	Hierarchical regression modeling adjusted by age and sex	Children with higher educated mothers had lower BMIs, higher handgrip strength and higher aerobic fitness; their parents reported healthier food consumption, and less exposure to smoking. SES differences in handgrip strength, aerobic fitness and sleep duration were larger in older than in younger children

Tomaz et al. (2019)	Cross sectional. 259 children (3-6 y-old). South Africa	Fundamental Motor Skills (FMS) were assessed by The Test of Gross Motor Development-Edition 2 (TGMD-2) that consists of six locomotor skills (run, gallop, hop, leap, horizontal jump, slide) and six object control skills (catch, roll, throw, strike, stationary dribble, kick)	SES was indicated by region income settings (urban high-income (UH), urban low-income (UL), and rural low-income settings (RL))	Multiple linear regressions adjusted by age and sex	Most of the children were classified as having "average" or "high" locomotor and object control skills. No association was found between SES and FMS
Morley et al. (2015)	Cross sectional. 369 children (4–7 y-old). England	Motor proficiency was assessed using the Bruininks-Oseretsky Test of Motor Proficiency, Second Edition Brief Form (BOT- 2 BF): fine motor precision, fine motor integration, manual dexterity, bilateral co-ordination, balance, speed and agility, upper body co-ordination and strength	school SES (low, medium, high) was calculated for each participating school by collecting United Kingdom’s Indices of Multiple Deprivation (IMD)	Multivariate analysis of covariance (MANCOVA) adjusted by age.	Girls outperformed boys for fine motor skills and boys outperformed girls for catch and dribble gross motor skills. For fine motor skills, High SES significantly outperformed middle and/or low SES for fine motor precision, fine motor integration, manual dexterity, and fine motor total. For gross motor skills, High and middle SES outperformed low SES for speed and agility, upper body strength and gross total.
Merino-De Haro et al. (2018)	Cross sectional. 2,638 preschoolers (3–5 y-old). Spain	Musculoskeletal fitness (handgrip; Standing long jump); Aerobic Fitness (shuttle run test 20m); speed/ agility (4x10m shuttle run test). Body composition: body mass index (BMI), waist circumference (WC), and waist-to-height ratio (WHtR)	Parental educational level; Parental occupational level; Marital status	Binary logistic regression adjusted by age and sex.	Preschoolers whose parents (individually and both together) had high SES levels may have lower odds of becoming obese and of having a low musculoskeletal fitness compared to those of low SES.

Antunes et al. (2018)	Longitudinal. 272 children (3-5 y-old). Portugal	The Preschool Test Battery assesses a combination of motor skills (object control skills: catching and throwing a tennis ball) and physical fitness (agility: scramble test; speed: 40ft test; lower body muscular fitness: standing long jump; balance: balancing blocks) tasks	SES of the family (low, average, high) was based on parental occupation, educational level, income, housing conditions and residential area features. Geographical area (Urban, Semi-urban, Rural) were obtained following the criteria developed by Statistics Portugal	Hierarchical regression modeling adjusted by sex and body composition	Children from low SES performed better than high SES peers in tennis ball throw for distance. Rural children were better performers than urban peers in standing long jump. Rural area at baseline (time 0) was also predictor of standing long jump and tennis ball throw for distance at time 1 and 2.

A large-scale cross-sectional study conducted in the USA with children aged 11-14 years (JIN; JONES-SMITH, 2015), analyzed the association between household SES and children's physical fitness. The Fitnessgram battery measured the aerobic and non-aerobic components of physical fitness and, for SES, the eligibility for free meals, a proxy for family income. The results indicated that children from families with lower SES tended to have lower levels of physical fitness and presented a higher risk of obesity than children from families with higher SES. In another cross-sectional study in the USA, Wolfe, Lee, and Laurson (2020) used a nationally representative sample of children and adolescents aged between 3 and 15 years to analyze the relationship between SES and aerobic and non-aerobic fitness, regardless of gender, race, and level of participation in physical activities. The results indicated that, on average, the highest SES group had better physical fitness profiles than the moderate and low SES groups. In addition, children in the low and moderate SES groups had 60% and 70% higher chances of being classified as having low non-aerobic fitness, respectively.

In Europe, a study involving adolescents from 9 countries (PAVÓN et al., 2010) suggested that a high SES (index of material conditions in the family) was associated with higher levels of aerobic and non-aerobic physical fitness (muscle strength). However, in Portugal, the longitudinal study by Freitas et al. (2007) found that the association between SES and physical fitness in children and adolescents (5 cohorts: 7-9; 10-11; 12-13; 14-15; 16-18 years of age) varied according to the component of physical fitness and with age. In some age groups (age intervals), high SES students had better muscle strength and speed/agility (non-aerobic components). In comparison, low SES children had better flexibility (non-aerobic physical fitness component) and aerobic physical fitness.

Studies carried out in South America also showed contrasting results. For example, a cross-sectional study in Brazil (GUEDES et al., 2012) showed that, in a sample of children and adolescents aged 6 to 18 years, the SES of families was inversely associated with children's physical fitness. In addition, high SES children were more likely to perform poorly on physical fitness tests. In Colombia, Otero et al. (2017) used a representative sample of young people aged 8 to17 years to identify sociodemographic factors associated with muscle strength (handgrip; non-aerobic component of physical fitness). The results indicated that having low muscle strength was associated with indicators of high SES (dwelling in an urban area and a high-class neighborhood, in addition to parents with a high level of education – high school or college).

On the other hand, a cross-sectional study with a large sample of adolescents in Colombia (SANDERCOCK et al., 2017), analyzed the relationship between aerobic and non-aerobic physical fitness and SES. There were two SES measures: family income and a regional SES indicator (classified as low, medium, or high) that considered socioeconomic aspects of the region, housing conditions, and access to public services. The authors found that non-aerobic physical fitness (upper limb muscle strength - handgrip test) was associated with the regional indicator of SES, which was not observed for aerobic physical fitness. Nonetheless, family income was not associated with any measure of physical fitness.

A cross-sectional study in the Netherlands (VERMEIREN et al., 2018) analyzed socioeconomic inequalities in multiple health-related domains in 1,403 children between 4 and 12 years of age. Measures comprised: physical fitness (aerobic/non-aerobic, body mass index), healthy behaviors (amount of moderate to vigorous physical activity; sleep duration, exposure to tobacco; consumption of healthful foods), mental health (Strengths and Difficulties Questionnaire - SDQ), and school absenteeism. The SES was assessed using maternal educational level and a material deprivation index. The results indicated that children whose mothers had a higher educational level had higher physical fitness and lower body mass index than those with lower educated mothers. In addition, these high SES children presented several positive health outcomes: lower mental difficulties, lower school absenteeism, greater consumption of healthy foods, and less exposure to tobacco. Analyzes using the material deprivation index showed results in the same direction. Additional analyzes from this same study indicated that, in older children, the inequalities between the low and high SES groups for measures of physical fitness and sleep became larger.

The literature investigating the relationship between physical fitness and SES has advanced, to a greater degree, in populations of older children and adolescents. However, in preschool children, the focus has been to analyze the relationship between SES and motor skills. Two systematic reviews that analyzed environmental factors related to the development of fundamental motor skills presented contrasting results. Venetsanou and Kambas (2010) indicated a consistent association between SES and gross motor skills. Children from low SES regions had lower performance than children from high SES regions. On the other hand, the review by Barnett et al. (2016) reported this association as inconsistent, given that a high SES was positively associated with only some aspects of motor competence (understood as the ability to combine gross and fine motor skills).

Similarly, a cross-sectional study in South Africa (TOMAZ et al., 2019), investigated the performance in fundamental motor skills (FMS) of 259 children aged 3-6 years, considering schools in high and low SES areas. The results suggest that most children in the sample have adequate levels of FMS, and the SES measure was not associated with motor performance in the FMS tests.

Still, evidence from high-developed countries suggests that the motor performance of preschool children from low SES families is lower than children from high SES families (CHOW; LOUIE, 2013). For example, a cross-sectional study in England (MORLEY et al., 2015) assessed the motor skills of 369 children aged 4-7 years, considering sex and SES. The Bruininks-Oseretsky Test of Motor Proficiency 2nd Brief Form (BOT-2 BF) assessed motor competence, which contains both gross and fine motor skills tasks (manual dexterity, bilateral motor coordination, and stability motor skills) and components of non-aerobic physical fitness (balance, speed, and agility, muscle strength). The SES measure (low, medium, and high) comprised an index with family income, educational level, and access to essential public services (IMD - Indices of Multiple Deprivation). The results indicated that the high and medium SES groups had better motor skills performance than the low SES group. Regarding gender, girls performed better in fine motor skills, while boys performed better in bilateral motor coordination tests. Furthermore, other studies pointed out that a large proportion of preschool children from low SES families presented delayed motor development (GOODWAY; ROBINSON; CROWE, 2010; POPE; LIU; GETCHELL, 2011).

Few studies have analyzed the relationship between SES and physical fitness components in preschool-age children. A cross-sectional study using data from the PREFIT project in Spain (MERINO-DE HARO et al., 2019) analyzed the relationship between SES, body composition, and physical fitness with a sample of 2,638 three-to-five-year-old children. Physical fitness components included aerobic fitness, speed/agility, and upper/lower body muscular strength. The SES measure comprised the educational and occupational level of the parents. Concerning body composition, the results indicated that children whose parents had a higher educational level and jobs with higher qualifications had lower chances of being obese. The results also showed that children whose parents had a high SES were less likely to have low non-aerobic physical fitness.

The three years longitudinal study by Antunes et al. (2018) analyzed the relationship between SES and motor performance of 272 children aged 3 to 5 years (“Madeira Child Growth Study” – Portugal). Motor performance was assessed with The Preschool Test Battery, a combination of motor skill (throwing and catching the tennis ball) and physical fitness (agility, speed, lower limb strength, and balance) tasks. The SES of the families was classified as low, medium, or high, based on an index composed of information on the educational and occupational level of the parents, housing conditions, and the region in which they live. In addition, another SES measure included information on the geographic area (urban, semi-urban, and rural). The results indicated that children with low SES had better performance in the tennis ball throw compared to children with high SES. However, no other association was found between SES and performance in the remaining motor skills and physical fitness tasks. Regarding the geographic area, children from rural areas performed better in the lower limb muscle strength test (standing long jump). The rural area also proved to be a future predictor for motor performance (standing long jump and tennis ball throw).

Although SES is considered a significant factor associated with health outcomes in societies (CSDH, 2008), the studies selected in this section present mixed results for the relationship between SES and physical fitness in children and adolescents. This inconsistency in the results can be attributed to the wide age range in the studies (FREITAS et al., 2007) and differences in the studies' methodologies, such as the diverse instruments for measuring SES and physical fitness, sample selection strategies, and statistical analysis.

2.3 Physical fitness, physical activity and cognition in children and adolescents

The first years of a child's life are considered a crucial phase of brain development and cognition, as it is during this period that more intense moments of neuroplasticity[3] occur, called "critical" or "sensitive" periods (KNUDSEN, 2004; LENT; OLIVEIRA, 2018). Understanding factors that can promote healthy cognitive development in

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[3] Neuroplasticity may be defined as the ability of the brain to adapt to external stimuli undergoing temporary or permanent changes, and it exists in many different, simultaneous levels (TOVAR-MOLL; LENT, 2016)

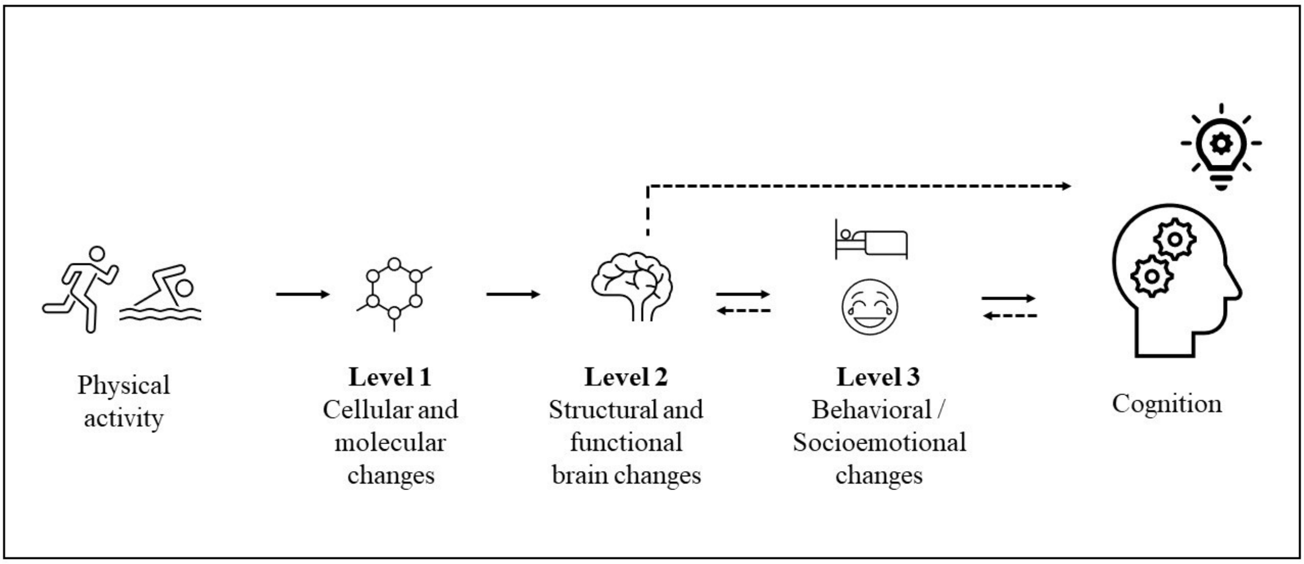
childhood is of great importance, given the relationship between cognition and different outcomes throughout life such as better social and emotional relationships, health, personal finances, and involvement in crimes (MOFFITT et al., 2011).

Physical activity and physical fitness are two health-related concepts considered as potential factors related to cognition in preschool-age children (PATE et al., 2019). Some evidence from systematic reviews and meta-analyses suggests that higher levels of physical fitness and physical activity can promote higher academic performance and improved cognitive functions (CASTELLI et al., 2014; SIBLEY; ETNIER, 2003; ST. LAURENT et al., 2021). However, the mechanisms responsible for the relationship between physical activity, physical fitness, and cognition are not fully established. The review by Stillman et al. (2016) presents a conceptual model with multiple levels of analysis of the mechanisms of the relationship between physical activity, physical fitness, and cognition (Figure 2.1). Initially, Level 1 would correspond to molecular and cellular mechanisms. Concerning this, physical activity would modulate the secretion of substances (growth factors) such as BDNF, IGF-1, VEGF, and other neurotransmitters, such as serotonin, responsible for energy maintenance and synaptic plasticity (COTMAN; BERCHTOLD; CHRISTIE, 2007; FABEL et al., 2003; HAMILTON; RHODES, 2015). These growth factors, in turn, would cause complex cellular changes including the development of new blood vessels (angiogenesis) and the development of new neurons (neurogenesis) (COTMAN; BERCHTOLD; CHRISTIE, 2007).

At level 2, the mechanisms describe changes in structures (morphology) and brain functions. In this sense, some studies indicate that individuals with higher physical fitness would present greater volumes of brain structures (gray and white matter), which are related to higher levels of cognitive performance (CHADDOCK et al., 2010; MAKIZAKO et al., 2015). Furthermore, regarding brain functioning, physical activity could influence cognition through an optimal functional allocation of neural resources (i.e., functional activation) during cognitive tasks (CHADDOCK-HEYMAN et al., 2013).

Finally, level 3 of the conceptual model addresses more macroscopic changes related to behavioral mechanisms that could mediate improved cognition through physical activity. These behavioral mechanisms include better sleep quality (WILCKENS; ERICKSON; WHEELER, 2018), improved mood, and lower depressive symptoms (ALBINET et al., 2016). The authors of this conceptual model (STILLMAN et al., 2016) also indicate that the mechanisms listed at each level of analysis are not mutually exclusive, with bidirectional effects between them.

Figure 2.1: Conceptual model of mechanisms of physical activity at multiple level of analyses



Adapted from: Stillman et al. (2016)

Next, we present studies that investigated the relationship between physical activity or components of physical fitness and executive functions or academic performance in children and adolescents. In general, we found a positive relationship between these variables. Box 2.2 summarizes the main characteristics of the studies presented in this section.

Box 2.2: Descriptive characteristics of studies investigating the relationship between physical fitness and cognition

Author	Study design / Participant's characteristics / Location	Assessment of Physical Fitness	Assessment of Cognition	Analyses	Main Results
Kao et al. (2017)	Cross-sectional. 79 children 9-11-yr-old. USA	Aerobic fitness: A modified Balke protocol used a motor-driven treadmill; Muscular fitness: Individual muscular fitness was determined using a full-body battery of assessments consisting of upper body, lower body, and core exercises	Working memory: child-friendly serial n-back task; Academic performance (Mathematics and reading): test questions from the Grades 3–5 California Standards Test forms	Linear hierarchical regression adjusted by age, grade, sex, BMI, IQ, and SES	Aerobic fitness was associated with working memory and mathematic performance (algebraic functions). Muscular fitness was associated with working memory.
Sardinha et al. (2016)	Longitudinal. 1286 students 9-14 yr-old (baseline). Portugal	Aerobic Fitness was assessed by the Progressive Aerobic Cardiovascular Endurance Run (PACER) from the Fitnessgram test battery	Academic performance (low, average, high) was assessed using students' marks at the end of the academic year at baseline and at follow-up 3 year later, in Portuguese, mathematics, foreign language (English), and science.	Ordinal regressions adjusted by age, BMI, academic performance at baseline	Students consistently fit increased the likelihood of having high levels of academic achievement in Portuguese, and foreign) compared with those consistently unfit. Those that were unfit at baseline and improved their aerobic fitness and became fit at follow-up had also higher odds of achieving better marks than those consistently unfit in Portuguese and foreign language.

Aadland et al. (2017)	Longitudinal. 1129 children 10 yr-old. Norway	Aerobic fitness was measured with an intermittent practical running field test (the Andersen-test); Motor skills were measured using a battery of three tests: (1) Catching with One Hand (Catching), (2) Throwing at a Wall Target (Aiming), and (3) Shuttle Run, 10 × 5 m (agility); Physical activity and sedentary time were measured by accelerometers	Academic performance in numeracy, reading, and English was measured using specific standardized Norwegian National tests. Executive Functions: inhibition (Stroop Color and Word Test); cognitive flexibility (Semantic Verbal Fluency test and The Trail Making Test); working memory (digit span test)	Structural equation modeling was used to examine the mediation models between predictor variables and outcome variables adjusted by age, sex, body fat, SES.	Indices of physical activity did not predict executive function and academic performance. A modest mediation effect of executive function was observed for the relation between motor skills and academic performance (numeracy).
Davis et al. (2011)	RCT. 171 children (CG=60; IG1=55; IG2=56) 9 yr-old. USA	Aerobic exercise intervention (12 weeks): Control Group (CG) sedentary activities; Intervention Group 1 (IG1): 20 min 5 d/wk; Intervention Group 2 IG2: 40 min 5 d/wk	Executive functions (Cognitive Assessment System); academic performance (Reading / Mathematics; Woodcock-Johnson Tests of Achievement III) and Brain activity (Functional magnetic resonance imaging - fMRI)	Intent to treat analysis of covariance tested group differences on cognition and achievement at posttest, adjusting for race, parent education, and baseline score.	Aerobic exercise improved executive function and mathematics performance (IG1 and IG2 compared to CG). Increased brain activity (prefrontal cortex activity and reduced posterior parietal cortex activity - regions related to executive functions) due to the exercise program were observed.

Houwen et al. (2017)	Cross-sectional. 153 children 3-5 yr-old. Netherlands	Motor performance was assessed with the MABC-2 (Manual Dexterity, Aiming and Catching, and Balance)	Executive Function was reported by parents with the Behaviour Rating Inventory of Executive Function–Preschool version (BRIEF-P). Parent-reported ADHD symptoms were assessed using the Hyperactivity-Inattention subscale of the SDQ	Hierarchical regression analyses adjusted by age, gender, SES, and ADHD symptomatology	Compared to their typically developing peers, children who are at risk for motor coordination difficulties showed significantly lower scores on the Working Memory subscale and performed significantly worse on the Planning / Organize subscale
Son and Meisels (2006)	Longitudinal. 12,583 children 4-6 yr-old. USA	Motor skills were assessed with the ESI-R (visual motor - copying simple figures; and gross motor - balancing, hopping, skipping, and walking backwards)	Academic performance was assessed in the domains of reading and mathematics using direct cognitive assessments developed by the National Center for Education Statistics (NCES)	Hierarchical regression analyses adjusted by age, gender, SES, and baseline cognitive scores	Baseline motor skills (early kindergarten), especially visual motor skills, predicted academic performance in reading and mathematics at the end of first grade.
Wang et al. (2014)	Longitudinal. 62,944 children 1.5-3 yr-old. Norway	Mothers completed questionnaires on their child’s motor skills: gross motor skills at 1.5 years (walking independently) and at 3 years (kick a ball without support, catch a large ball with both hands), fine motor skills at 1.5 years (throw a small ball, stack a small block on top of another, turn the pages in a book by himself/herself) and at 3 years (hold a pencil "like an adult", unbutton a shirt).	Mothers completed questionnaires on their child’s communication skills at 1.5 years (follow simple commands; receptive vocabulary) and at 3 years (advanced receptive vocabulary, interpretation of single pictures in a book)	Structural equation modeling adjusted by child’s health status at birth, SES, and maternal psychological distress	Communication and motor skills were highly correlated at 1.5 years. Motor skills at 1.5 years predicted communication skills at 3 years positively

Piek et al. (2008)	Longitudinal. 33 children 6-11 yr-old. Australia	Ages and stages questionnaires (ASQ) assessed fine and gross motor trajectory of the participants from birth to 4 years. The fine motor and gross motor performance at 6–11 years was assessed using the McCarron assessment of neuromuscular development (MAND)	Assessment of cognitive development (verbal comprehension, processing speed, working memory, perceptual reasoning) was conducted using the Wechsler intelligence scale for children – fourth edition (WISC-IV)	Hierarchical regression analyses adjusted by age, SES, and baseline cognitive scores	The ASQ gross motor trajectory showed a significant predictive relationship with executive functions (working memory and processing speed)
Niederer et al. (2011)	Longitudinal. 217 children 4-5 yr-old. Switzerland	Aerobic fitness was assessed with the 20-m shuttle run test. Non-aerobic fitness: Agility was assessed with obstacle course (time in sec) and dynamic Balance used the performance in a balance beam (number of successful steps)	Executive functions: Spatial working memory from Intelligence and Development Scales (IDS)and, attention from Konzentrations-Handlungsverfahren für Vorschulkinder (KHV-VK)	Hierarchical linear models adjusted by BMI and Sociocultural characteristics (immigrant status, parental education)	Aerobic fitness was positively associated with Attention; Agility was not associated after adjustments; Dynamic balance was positively associated with Spatial working memory.
Wick, Kriemler, and Granacher (2021)	RCT. 54 children (CG=22; IG=32) 4-6 yr-old. Germany	Strength-Dominated Exercise Program (10 weeks): CG: waiting list; usual kindergarten curriculum (1 d/wk, 30 min each session); IG: 3 d/wk, 30 min each session. Physical Fitness tests: Lower body strength (standing long jump); Upper-body strength (Handgrip strength test); Static Balance: (single-leg stance test); Coordination (the hopping on right/left leg test)	Executive functions: Attention was assessed using the Konzentrations-Handlungsverfahren für Vorschulkinder (KHV-VK)	Analyses used a separate 2 (“group”: INT vs. CON) X 2 (“time”: pre vs. posttest) repeated-measures analysis of covariance (ANCOVA).	IG had larger gains in jump performance and concomitant trends toward improved attentional span compared with active CG children who followed the regular kindergarten curriculum.

Chang et al. (2013)	RCT. 26 children 6–7.5 yr-old (CG=13; IG=13). Taiwan	IG: aerobic and motor skill (moderate intensity of soccer); CG: motor skill (low intensity of soccer); 2 d/wk for 8 wks, 35 min each session. Physical fitness tests:1) Core muscular endurance (60-s crunch curl up), 2) Lower body muscular fitness (standing long jump), 3) Balance (standing on one leg with eyes closed); 4) Flexibility (sit-and-reach); 5) Body composition (BMI)	Executive function: inhibitory control (Eriksen flanker test). Brain neuroelectrical activity was assessed using event-related potential (ERP)	A 2 (group: low-exercise intensity vs moderate intensity) X 2 (times: pre-test vs post-test) X 2 (condition: congruent vs incongruent) X 3 (site: Fz, Cz, vs Pz) mixed repeated measures ANOVA was further utilized to evaluate the flanker test performance and ERP measures	Children in IG demonstrated improved physical fitness components (core muscular endurance, flexibility, and body composition), while the CG only showed decreased body composition. All children had higher accuracy and faster reaction times in an inhibitory task following the coordinative exercise intervention (no significant differences were found between IG and CG). Higher neuroelectrical activation (greater P3 amplitude and shorter P3 latency) was found following the coordinative exercise in both IG and CG.

A cross-sectional study (KAO et al., 2017) investigated the relationship between components of physical fitness, and working memory in pre-adolescents, and demonstrated that both components of physical fitness were positively related to working memory. Academic performance measurements (mathematics and reading) were not significantly related to the non-aerobic component (musculoskeletal fitness), while the aerobic component was only related to the performance in mathematics A longitudinal study with 1,286 students from 14 public schools showed that adolescents who improved their aerobic fitness or remained in the healthy aerobic fitness zone for three years presented significantly better results in language but not in mathematics skills (SARDINHA et al., 2016).

Aadland et al. (2017) used data from the Active Smarter Kids trial in a sample of 1,129 10-year-old children, followed over seven months, to investigate if executive function mediated the prospective relationships between indices of physical activity and academic performance. They did not find any potential moderating influence of executive function on physical activity and academic performance; however, a small mediation effect of executive function was observed for the relation between motor skills and academic performance in mathematics. Similarly, Davis et al. (2011) examined the influence of participating in regular aerobic exercise (after school exercise program) on executive functions and academic performance in elementary school children in a randomized controlled trial. This study showed that physically active children who participated in 40 minutes of exercise per school day experienced significant improvements in mathematics performance as compared to sedentary peers after controlling for race, parent education, and baseline scores. In addition, brain areas associated with executive function (prefrontal and parietal regions) have shown greater activity in those physically active.

The evidence described suggests a differential relationship between physical fitness components and academic domains: some studies have reported positive links between aerobic fitness with mathematics, but not with reading, whereas others have found improvements in language but not in mathematics (DONNELLY et al., 2016). However, the systematic review by Singh et al. (2018) shows strong evidence for the beneficial effects of physical activity on mathematics performance. Still, for language, the evidence is inconclusive. Considering that executive functions tend to be stronger predictors of performance in mathematics than in language (PASCUAL; MOYANO;

ROBRES, 2019), in children between 5 and 10 years of age, one possible explanation is that executive functions could mediate the path in the physical fitness-cognition relationship, especially in mathematical skills (AADLAND et al., 2017; ALLOWAY; ARCHIBALD, 2008; ROEBERS et al., 2014).

Investigations focusing on early childhood also indicate positive relations between physical fitness components and cognition domains. In a cross-sectional study, children at risk for motor coordination difficulties, assessed with the Movement Assessment Battery for Children-2, showed significantly worse performance in executive functions (rated by parents) compared with typically developing children, independent of age, sex, socioeconomic status and attention-deficit-hyperactivity disorder (ADHD) symptomatology (HOUWEN et al., 2017).

Son and Meisels (2006) used data from a longitudinal survey of a nationally representative sample of more than 12,000 children in the USA, from the beginning of preschool to the end of 1st grade of elementary school, to examine the relationship between motor skills and academic achievement. Results revealed that early fundamental motor skills (measured using the Early Screening Inventory-Revised) were small but significant predictors of later school performance in mathematics and reading. Similarly, in a comprehensive sample of 62,944 Norwegian children, motor skills at 18 months of age were shown to be modest predictors of language skills at age 3 (WANG et al., 2014). The information on the trajectory of gross motor skills from birth to 4 years of age is a significant predictor of both working memory and processing speed in school-aged children (PIEK et al., 2008). A longitudinal study (NIEDERER et al., 2011) with a sample of preschool children had shown that baseline results of aerobic (shuttle run test) and some non-aerobic fitness components (agility and dynamic balance) were associated with improvements in executive functions nine months later, where modest associations were observed between aerobic fitness with attention and dynamic balance with working memory.

Studies investigating the effects of physical activity programs on preschool children suggest these interventions may jointly benefit physical fitness and cognition aspects. In a sample of 26 6- to 7-year-old children in Taiwan, Chang et al. (2013) analyzed the impacts of a coordinative exercise intervention (soccer program) with different exercise intensities on executive function. After 8 weeks, children in the moderate intensity group improved some components of non-aerobic physical fitness (muscular endurance, flexibility, body composition), while the low intensity group only showed better body composition profiles. Regarding the measures of inhibitory control (executive function), all children had higher brain neuroelectrical activation and, higher accuracy and faster reaction times in an inhibitory task after the intervention. Similarly, Wick, Kriemler, and Granacher (2021) examined the effects of an exercise program on enhancing different aspects of physical fitness (muscle strength/power, balance, coordination, and motor skills) and cognitive performance in preschool children. The results suggest that the intervention group (10-week exercise program) had higher gains in jump performance (muscle power), with a similar trend toward improvements in attentional capacity, compared with active control children who followed the regular kindergarten curriculum of preschool children.

The evidence presented suggests positive associations between motor (physical fitness components; motor skills) and cognitive dimensions. However, in Brazil, we have few studies with a longitudinal design that makes it possible to observe the same phenomenon properly. This thesis aims to address this gap.

2.4 School's effect on non-cognitive dimensions

Since the Equality of Educational Opportunity report, James Coleman's seminal work (COLEMAN et al., 1966), the scientific interest in finding school factors associated with student performance has grown. This information can help policymakers implement effective education programs. Studies on "school effect" or "school effectiveness" after Coleman's report had a greater focus on factors related to school infrastructure and management, teacher performance, and characteristics of the students' social background (MORTIMORE et al., 1988; RUTTER et al., 1979). Furthermore, students' academic and cognitive performance was generally the main component considered a school result.

In contrast to the view that school effectiveness studies are "closely focused on cognitive outcomes" (WEST; SWEETING; LEYLAND, 2004), some systematic reviews have analyzed the effect of school on non-cognitive dimensions, such as some health-related behaviors. For instance, in a systematic review of studies that used multilevel models to investigate different school effects, Sellström and Bremberg (2006) pointed out other results beyond academic performance. They highlighted healthy behavior outcomes, such as: smoking and alcohol consumption, well-being, behavioral problems, and physical activity. However, only one study in this review assessed a result related to motor development. This study suggested that quality physical education teachers and the administration of physical fitness tests are factors related to 8- to 9-year-old children's aerobic fitness (ZHU, 1997).

Similarly, the systematic review by Bonell et al. (2013) investigated the effects of schools and school environment interventions on students' health. The selected studies also addressed health-related behaviors (smoking, drinking alcohol, use of marijuana, group fighting, physical activity during school hours). In this review, the cross-sectional study by Cradock et al. (2007) in the USA reported that 12-to-14-year-old students schools attending with a larger total campus and playground areas per student showed higher levels of physical activity during school hours as measured by accelerometers. Additionally, in the same review, results from three studies examining effects of improving playgrounds design and structure on children's physical activity levels (RIDGERS et al., 2007; RIDGERS; FAIRCLOUGH; STRATTON, 2010; STRATTON; MULLAN, 2005) indicated increased children's daily physical activity levels in the short term. Thus, these reviews suggest a gap concerning the evidence on the effect of school on motor dimensions.

On the other hand, studies that analyzed programs to develop motor skills carried out in a school environment pointed to positive effects of interventions on the motor dimensions assessed. For example, Kriemler et al. (2011) carried out a review of systematic reviews on the impact of school interventions aiming to increase physical fitness or physical activity levels in children and adolescents. In the selected reviews, between 47% and 65% of the studies showed positive results in increasing the level of physical activity. However, only in one of the reviews, 60% of the studies had shown positive results in aerobic fitness. Although the search criteria included a comprehensive age group (4-18 years), only one study analyzed preschool-age children.

Veldman, Jones, and Okely (2016) reviewed the effectiveness of physical activity programs for developing gross motor skills in preschool-age children (3-5 years) and found that 86% of the studies had positive results. On the other hand, the number of studies in this age group was low. Likewise, the systematic review by Zeng et al. (2017) pointed out that 80% of physical activity programs focused on motor skills reported positive results in preschool children. Furthermore, Van Capelle et al. (2017) also indicate that interventions promoted by trained teachers show higher gains in motor skills compared to interventions applied by external professionals or exclusively by family members. Similarly, UNESCO highlights the central role of well-qualified teachers towards quality physical education and better opportunities for motor development (UNESCO, 2015).

Box 2.3 presents interventions that aim to improve fundamental motor skills and physical fitness in preschool-age children. Generally, the selected studies suggest positive results in the investigated motor dimensions.

Box 2.3: Descriptive characteristics of studies investigating the effects of physical activity interventions on children’s motor skills and physical fitness

Author	Study design / Participant’s characteristics / Location	Testing/setting/dose	Outcomes	Exposure	Main Results
Reilly et al. (2006)	545 children 4 yr-old (IG=268, CG=277). Scotland.	Baseline, 6 and 12 months; childcare settings; 3×30’ sessions per week for 24 weeks	Motor skills: jumping, balance, skipping, and ball exercises measured via Movement Assessment Battery.	Intervention group received enhanced physical activity program plus home-based health education aimed at increasing physical activity through play and reducing sedentary behavior, while control group received usual curriculum	The intervention group had significantly higher performance in movement skills than control group at six-month follow-up
Jones et al. (2011)	97 children 4 yr-old (IG=52, CG=45). Australia.	Pre-post; childcare setting; 3×20’ sessions per week for 20 weeks	Movement skill competence (running, hopping, jumping, catching, kicking) assessed via TGMD-2	Intervention group received structured activities, while control group received usual curriculum activities (free play)	The intervention group showed greater improvements in movement skill proficiency compared with the control group

Puder et al. (2011)	652 children 4-5 yr-old (IG=342; CG=310). Switzerland	Pre-post; school setting; 4x45' sessions per week from August 2008 to June 2009	Aerobic fitness (20-m shuttle run test); agility (obstacle course - time in sec); balance (number of successful steps in the balance beam); adiposity (bioelectrical impedance analysis); physical activity (accelerometers)	Intervention group received a multidimensional lifestyle treatment (physical activity, nutrition, media use, and sleep), while control group did not receive any treatment and continued their regular school curriculum	The intervention group showed greater improvements in aerobic fitness, agility, and beneficial effects on adiposity
Bonvin et al. (2013)	678 children 2-4 yr-old (IG= 313; CG= 201). Switzerland	Pre-post; school setting; 9 months	Motor skill measures were adapted from the Zurich Neuromotor Assessment (climbing up and down the stairs; running; balancing; getting up; landing after jumping); physical activity (accelerometers); body composition (BMI)	Intervention group received a governmentally led center based childcare physical activity program (real-life), while control group received no intervention	The intervention group showed no significant increase in motor skills compared to the control group
Roth et al. (2015)	709 children 4-5 yr-old (IG= 368; CG= 341) Germany	Pre-post and follow-up; school setting; 5×30' sessions per week and PA homework 1 or 2x per week for 11 months	Motor skills: agility (obstacle course); lower body strength (standing long jump); balance (balancing on one foot); coordination (jumping-to-and-fro-sidewise); physical activity (accelerometers); body composition (BMI)	Intervention group received a multicomponent intervention program focused on enhance physical activity and motor skill performance while control group received regular curriculum activities	The intervention group showed significant increase in motor skills compared to the control group at postintervention and at follow-up

Ruiz-Esteban et al. (2020)	136 children 3-5 yr-old (IG= 28; CG= 108). Spain	Pre-post; school setting; 2x45’ sessions per week for 24 weeks	Leg coordination (walking backwards, on tiptoe, on a straight line, staying on the right foot, staying on the left foot, and rhythmically jumping on either foot) and arm coordination (bounce a ball catch a beanbag, target shooting) was assessed via The McCarthy Children’s Psychomotricity and Aptitude Scales (MSCA)	Intervention group received an educational psychomotor program focused to improve fundamental motor skills while control group received usual curriculum activities (free play)	The intervention group showed greater improvements in leg and arm coordination compared with the control group.
Navarro-Patón et al. (2021)	15 children 4-5 yr-old (IG= 76; CG= 76). Spain	Pre-post; school setting; 1x40’ session per week for 06 weeks	Manual dexterity, aiming and catching and balance assessed via MABC-2	Intervention group received structured activities focused on manual dexterity, aiming, grip and balancing, while control group received usual PE curriculum in preschool education in Spain (i.e., the body and body image, play and movement, daily activity, and personal care and health)	The intervention group showed significant increase in aiming and catching, balance and total score compared to the control group.

Ali et al. (2021)	66 children 3-4 yr-old (IG= 46; CG= 20). New Zealand	Pre-post and follow-up; school setting; 1x45’ session per week for 10 weeks	Movement skill competence (running, hopping, jumping, catching, kicking) assessed via TGMD-2	Intervention group received a fundamental motor skills program, while control group (waiting list) received only guidance for physical activity	The intervention group showed significant increase in locomotor and object control skills compared to the control group. Locomotor and object control skills were maintained by the children in the IG group during the follow-up period (3 months)

A cluster randomized controlled trial (REILLY et al., 2006) investigated an enhanced physical activity program in 36 nurseries in Scotland that aimed to reduce body mass index, increase the performance on fundamental motor skills, and physical activity levels. Of the 545 children (4 years old) who entered at baseline, 277 were allocated in the control group (CG) and 268 in the intervention group (IG). The intervention was carried out with two elements: i) an institution element, consisting of 30-minute physical activity sessions three days a week over 24 weeks; ii) a home element consisting of a resource pack of materials with guidance on linking physical play at nursery and at home plus information encouraging the families to reduce sedentary behavior. Although there was no significant effect on body mass index and physical activity levels measures, the intervention group presented a significantly higher performance in fundamental movement skills than the control group at follow-up.

In Australia, Jones et al. (2011) assessed the efficacy of a 20-week physical activity program for four-year-old preschool children to improve fundamental motor skills and physical activity levels and reduce body mass index. Each week, the intervention group (IG=52) received three sessions of 20-min structured lessons focused on fundamental movement skills (running, hopping, jumping, catching, kicking; one in each session). The control group (CG=45) followed the usual curriculum activities, including outside free playtime. At follow-up, compared with children in the control group, children in the intervention group showed greater improvements in movement skill proficiency (total score of all fundamental movement skills) and significantly greater increases in physical activity levels during the preschool day.

Two studies from Switzerland that investigated physical activity interventions in preschool children found mixed results. Puder et al. (2011) assessed the effect of a multidimensional lifestyle intervention on physical fitness components and adiposity in preschool children. The one-year intervention (IG=342) consisted of a physical activity program (four sessions of 45-min per week), lessons on nutrition, health media use, sleep recommendations, and adaptation of the preschool class environment to promote enhanced children's physical activity (fixed and mobile equipment). The comparative activities (CG=310) comprised a regular school curriculum, including one 45-minute physical activity lesson a week in the gym. Results presented a significant increase in aerobic fitness and motor agility in the intervention group compared with the control group. The intervention also contributed to beneficial effects in percentage body fat.

Bonvin et al. (2013) investigated the impact of a 9-month physical activity intervention on motor skills, body mass index, and physical activity levels of 648 two-to-four-year-old preschool children (IG= 313; CG= 201). The intervention was delivered in two levels. The individual-level consisted of training and support of the preschool staff, encouragement of parental involvement, and recommendations to integrate physical activity into the daily life of the childcare. Each childcare center received a budget ($1500) and advice from specialists to create an activity-friendly environment (rearrangement and acquisition of physical activity equipment) at the environment level. There was no specific mandatory time for daily physical activity or the use of structured movement lessons. Childcare centers allocated in the control group continued their usual curriculum and did not receive any intervention or financial incentives. The results indicated that the intervention does not improve motor performance outcomes (i.e., climbing up and down the stairs; running; balancing; getting up and landing after jumping), body mass index, and physical activity levels. Nevertheless, regarding the IG, the authors found that both free access to a movement space and the purchase of mobile physical activity equipment was related to better motor skills and higher physical activity levels.

Roth et al. (2015) examined the impact of an 11-month multicomponent preschool intervention to enhance physical activity and motor skill performance in 709 four-to-five-year-old German children. The intervention group (IG=368) received daily 30-min physical activity structured lessons (joyful games and exercise motor skill tasks) and physical activity homework cards once or twice per week (games and motor tasks designed to promote an active lifestyle for the family). The intervention also included educational components for parents and teachers (nutrition, limited media use, and the importance of physical activity in the early years). Children in the control group (CG=341) follow the regular preschool curriculum without teaching structured motor skills and enhanced physical activity. Results indicated that, compared with the CG, children in the IG presented a higher performance in the motor skills total score at the end of the intervention and the 2-4 months follow-up. However, regarding the physical activity levels, no difference was found between IG and CG at follow-up

Three recent studies had investigated the effects of programs focused only on motor development in preschool children. In Spain, Ruiz-Esteban et al. (2020) analyzed a motor skills program applied to 136 three-to-four-years-old children. The intervention group (IG=28) received structured sessions for 24 weeks (two sessions per week, during 45’). The sessions comprised activities for several aspects of fundamental motor skills (body perception and control, postural balance, general dynamic coordination, visual-manual coordination). The control group (CG=108) received usual kindergarten activity involving free play. The results indicated that both groups showed a significant improvement in limb coordination. However, the authors reported that structured physical activity is more effective than free play since the intervention group presented higher arm and leg coordination values than the comparison group.

Navarro-Patón et al. (2021) investigated the effect of a short six-week program on levels of motor competence in 156 four-to-five-years-old Spanish children. Unlike other studies, this intervention does not have extended physical activities sessions but instead replaced physical education classes in the experimental group (EG=76) with one 40' session per week, focused on fundamental motor skills. In the control group (CG=76), the physical education classes continued with the regular curriculum in preschool education in Spain. After the intervention, there were significant differences between the CG and IG in aiming and catching, balance and motor competence total score. These results suggest that children who received specific motor skills instruction are more likely to increase their motor development than through general activities in PE classes or free play.

In New Zealand, Ali et al. (2021) assessed the effect of a 10-week physical activity intervention on 66 three-to-four-years-old children's fundamental movement skills. The intervention group (IG=46) received one 45' session per week. The sessions comprised locomotor and manipulative skills in a fun and child-friendly design based on animal movements (e.g., 'gallop like a horse'). Also, physical activity homework was given to the child based on the specific animal of the current session. The comparative activities only involved physical activity advice to the children's teachers in the control group (CG=20). The results showed a significant improvement in locomotor and object-control skills for the IG compared to the CG. There was no significant change in the CG fundamental movement skills after the intervention. Furthermore, the IG maintained their fundamental movement skills in the 3-month follow-up assessments.

This section has presented evidence regarding the effect of school on non-cognitive dimensions. In general, systematic reviews on this topic (BONELL et al., 2013;

SELLSTRÖM; BREMBERG, 2006) presented results of studies aimed at health-related risk behaviors, especially in the adolescent population. Studies investigating the effect of physical activity programs in the school setting in preschool children suggest positive results in motor dimensions such as fundamental motor skills and physical fitness. However, the results indicated refer to extracurricular programs, not allowing a discussion about the effect of preschool on motor dimensions.

3 AIMS AND HYPOTHESIS

3.1 Overall aim

This thesis aims to contribute to the research area of Education by examining children’s non-aerobic physical fitness, a motor dimension aspect of child development, and its relationship with environmental factors and cognition.

3.2 Specific aims

The specific aims of the thesis are:

- To analyze the relationship between the non-aerobic physical fitness of children and the socioeconomic status of the families.
- To analyze the relationship between non-aerobic physical fitness and cognitive development during the first years of compulsory education.
- To investigate the impact of preschool on the development of non-aerobic physical fitness in children.

3.3 Hypothesis

- H_1: There is a significant positive association between the socioeconomic status of families and the non-aerobic physical fitness of children.
- H_2: There is a significant positive relationship between preschool children's non-aerobic physical fitness and future cognitive development.
- H_3: There is a significant difference in the non-aerobic physical fitness of children who attended preschool compared to those who have not.

4 MATERIAL AND METHODS

The current thesis was conducted as part of a larger research study named “Longitudinal study on children´s learning trajectory”. This chapter briefly describes the research project and provides the methods adopted to test the previously presented hypothesis. Detailed information regarding all three studies of the thesis will be presented in each specific chapter (Chapters 5-7).

4.1 The Longitudinal Study on children’s learning trajectory

The Longitudinal Study on children’s learning trajectory (hereafter, longitudinal study) was developed by the Educational Opportunities Research Laboratory (*Laboratório de Pesquisa em Oportunidades Educacionais* - LAPOPE) at the Federal University of Rio de Janeiro (*Universidade Federal do Rio de Janeiro* - UFRJ), whose main objective is to identify school and extracurricular factors associated with the development of children during preschool. For detailed information regarding the longitudinal study see Bartholo et al., (2020b, 2020a).

The project arose from the need to understand what children know and can do when they start compulsory education in Brazil. There was also an interest to estimate the effects of educational policies in Brazil's educational system through robust research designs with a greater degree of causal inference. The longitudinal study was approved by the Ethics Committee of UFRJ (*Plataforma Brasil*) in 2016 (document no. 1.625.525). Informed written consent was obtained from parents/guardians in addition to the children's oral consent.

The longitudinal study presented a probabilistic cluster sample (school as the primary sampling unit) stratified by characteristics of pre-school provision and local authority of the municipal system of the city of Rio de Janeiro[4]. There was a random selection of 46 schools[5] from the Rio de Janeiro Municipal System: 18 EDIs, 28 regular schools. In addition, there was the inclusion of one private nonprofit school associated with the city public system (total of 47 schools). All children enrolled in the first year of pre-school of the selected were eligible to participate in the research.

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[4] The two types of preschool provision in Rio de Janeiro's public educational system include: a) Child Development Centers (EDI), the main public policy for early childhood education/care in the city and b) regular or "traditional" preschools

[5] Margin of error of 11.6% at 90.0% confidence interval.

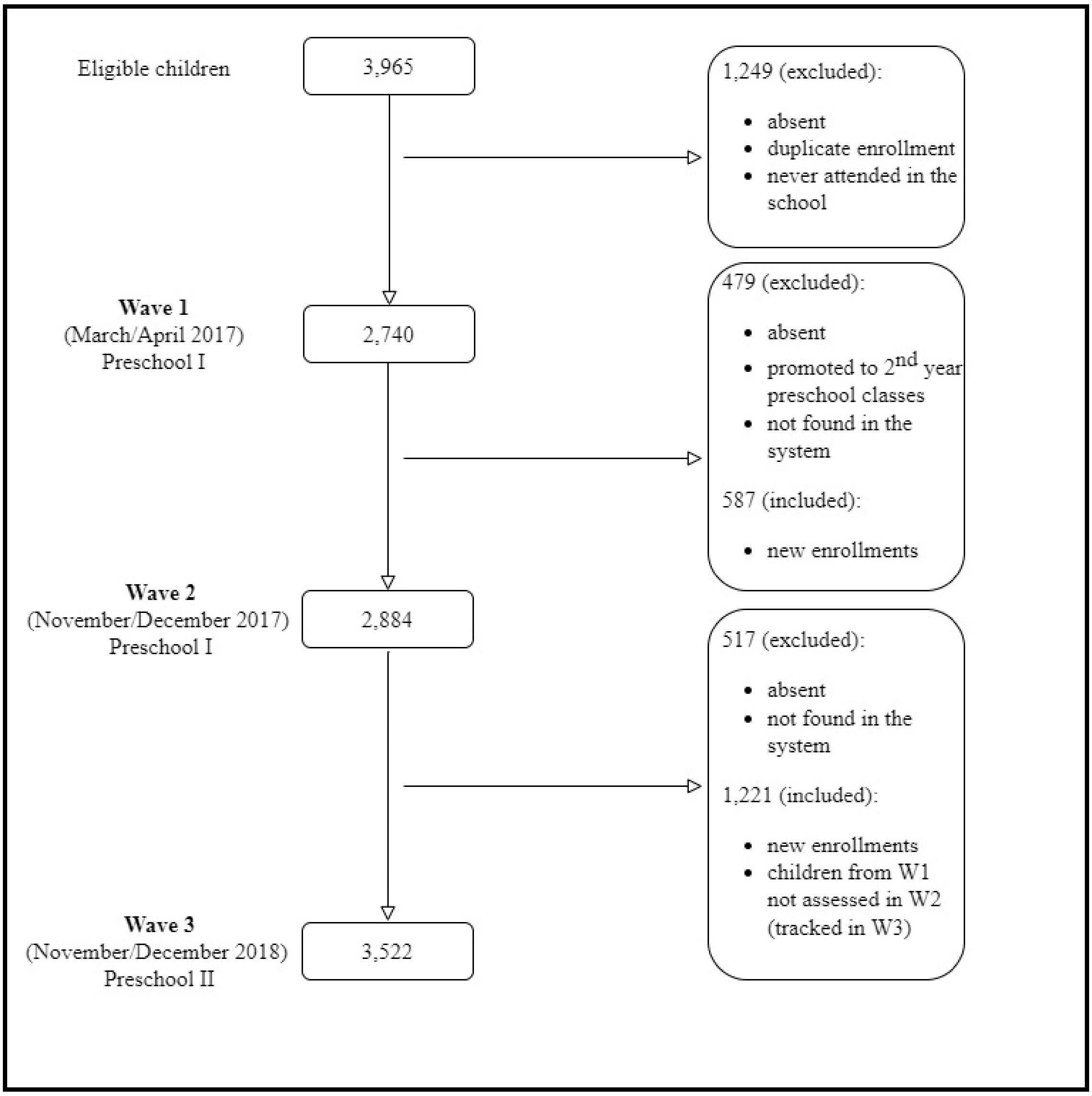
The longitudinal study adopted some strategies to monitor the children across the waves of data collection. First, all children enrolled in the schools randomly selected for the sample would be measured in all the waves, irrespective of whether they had moved to another Rio de Janeiro public school. Second, children who had migrated to private schools or other cities ceased to be part of the research. Third, children that had joined the randomly selected schools in the sample after starting the study were also tested.

Figure 4.1 shows the design of data collections: a) the Wave 1 at the beginning of the first year in school (March/April 2017); b) the Wave 2 at the end of the first year in school (November/December 2017); c) the Wave 3 at the end of the second year in school. Figure 4.1 also presents the flow of children through the two years of the project.

At the beginning of 2017, 3,965 children were eligible to participate in the study, considering the 47 selected schools. Nonetheless, this initial figure must be assumed with caution since the schools reported that some children had never attended the classrooms, and there were duplicate enrollments. The study started with a total number of 2,740 children assessed in Wave 1 (baseline). Given the strategies cited previously, the total number of children assessed in Wave 2 (2,884) was slightly higher than in Wave 1. Although 479 children in the baseline sample were not assessed (see table 4.1 for reasons), 587 children entered the study (new enrollments).

The total number of assessments was much higher at the third wave of data collection, comprising 3,552 children. Regarding Wave 2, there were 517 children not evaluated (see Figure 4.1 for reasons), and 1,221 joined in the final sample (new enrollments and tracked children from Wave 1 who were not assessed in Wave 2).

Figure 4.1: The longitudinal study’s design of data collection and flow of participants



Note: W1, W2 and W3 = Wave 1, Wave 2, and Wave 3, respectively.

Table 4.1 presents the mobility of the baseline sample of children among public schools and the attrition during the study's three waves of data collection. As mentioned before, the number of children assessed throughout the longitudinal project increased given two main reasons: i) new children that entered the schools in the sample between waves 1 and 3 of data collection were assessed; ii) children that were in the 47 schools of the sample that eventually moved to other schools between the 1st and 3rd wave of data collection were tracked and assessed.

Table 4.1: Number of cases in each wave and attrition

	N	N with Wave 1	Attrition
Wave 1	2740	---	---
Wave 2	2848	2261	17.5%
Wave 3	3552	2181	20.4%
Children with three measures (Wave 1, 2 and 3)	1935		29.4%

Source: LAPOPE/UFRJ, 2019.

4.2 Measured variables

This thesis uses several key variables throughout all its analyses, presented in more detail below.

4.2.1 Non-aerobic physical fitness

The non-aerobic physical fitness was assessed using the Sitting-Rising Test (SRT) (ARAÚJO, 1999). Through the assessment of the motor skills for both sitting and rising from the floor, the SRT evaluates the components of non-aerobic physical fitness (muscle strength, balance, flexibility, body composition) simply and reliably, presenting several advantages such as short application time (less than 5 minutes), high safety and meaningless cost (LIRA; ARAÚJO, 2000). SRT should be administered on a flat, non-slip surface. To perform the test, the individual must be barefoot, without socks and without clothing that may restrict their mobility. The evaluator requests that the individual, from the standing position, perform the action of sitting without using the hands (or supports) and without unbalance. On the ground, the evaluator requests that the individual perform the action of rising without using the hands (or supports) and without unbalance.

The measurement of the SRT consists of simply quantifying how many supports (hands and / or knees or, still, the hands on the knees or legs) the individual uses to sit and rise from the floor. Independent scores are given for each of the two acts - sitting and rising. The maximum score is 5 for each of the two acts. Half a point is subtracted for any noticeable unbalance. The best result of the two attempts for each act is chosen as representative of the individual. A composite score is obtained from the sum of the sitting and rising actions, allowing a total of 21 possible points on a scale ranging from 0 to 10 (0, 0.5, 1..., 9.5, 10). Previous studies have shown that SRT scoring is highly reliable in adult population (LIRA; ARAÚJO, 2000). Regarding the children population (4-5 years old), Ventista (2015) examined the validity of the SRT using the Motor Assessment Battery for Children – 2nd edition MABC-2) (HENDERSON; SUGDEN; BARNETT, 2007). Results indicated that SRT had high internal reliability contrasting with moderate internal reliability of the MABC-2. Additionally, the author found a moderate association between the SRT and MABC-2 and highlighted the advantages of SRT, like reliability, validity, low time-consuming, and the meaningless cost needed to be administered (VENTISTA, 2015).

4.2.2 Cognitive development (academic performance)

As argued previously, we can approach cognition through multiple processes and constructs. Therefore, the cognitive development was assessed considering the academic performance using an adapted version of the Performance Indicator for Primary Schools (PIPS) (BARTHOLO et al., 2020b, 2020a; TYMMS; MERRELL; HENDERSON, 1997; TYMMS; MERRELL; JONES, 2004). The instrument is composed of a set of dimensions of cognitive assessment measurements, such as: a) handwriting – the child is requested to write his name; b) vocabulary – identifying objects in a series of images; c) ideas about reading – to assess concepts about print; d) phonological awareness – rhymes and word repetition; e) identification of letters; f) recognition of words and reading – sentences and comprehension; g) ideas about mathematics – understanding of mathematical concepts; h) counting and numbers; i) addition and subtraction problems without symbols; j) shapes identification; k) digit identification; and l) mathematical problems including sums with symbols[6]. Measurements for the language (items “b” to “f”) and mathematics (items “g” to “l”) sections were constructed using Rasch modeling (BOND; FOX, 2015), using the Winstep software. This Rasch measure considers the number of correct items and their

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[6] For a more detailed presentation of the PIPS test, its potential uses and limitations, see (Tymms et al., 1997).

difficulty. For example, a complex correct answer adds a higher score to the cognitive measure than a simple item.

4.2.3 Body composition

Additional information for the height and weight of the children were collected for the calculation of the Ponderal Index (PI). The PI is a method that presents the relationship between weight and height with better consistency and mathematical logic than the body mass index. (RICARDO; ARAÚJO, 2002). Height was measured in the nearest millimeter (Alturexata stadiometer) and children were weighed to the nearest 0.1 kg (Lider portable scale P150), with bare feet and wearing light clothing. PI was calculated as height (cm) / $\sqrt[3]{}$ weight (kg). Height and weight were only collected once – during the Wave 1. The use of a body composition measure as a control variable is important because the actions of sitting and rising from the floor are a basic human movement which is related to muscle strength and power, lower limb flexibility, and motor coordination, and those are influenced by body dimensions (RICARDO; ARAÚJO, 2001).

4.2.4 Socioeconomic status (SES)

Families' socioeconomic status (SES index) was measured using a questionnaire applied to children's parents and guardians. For this, the SES index used items related to durable assets ownership and access to amenities (e.g., car, washing machine, computer, tablet, printer, internet, and cable TV services), parent's education level, household density, and poverty (beneficiaries of cash transfer programs). The SES index was constructed using Rasch modeling (BOND; FOX, 2015), using the Winstep software. The Rasch measure for the SES index considers the items presented before creating a single scale. A lower score indicates that the family has a low SES and vice-versa. In practical terms, parents with a higher educational level increase the SES score while a family beneficiary of cash transfer programs (a proxy for poverty) decreases the score. For further information regarding the use of the SES index, see Koslinski and Bartholo (2020) and Bartholo et al. (2020c).

4.3 Procedure during data collection

In each wave of data collection, children were individually tested (in small groups of two or three) in a quiet room at their school. The procedure initiates with the SRT, presented as a "challenge" to increase motivation and create a friendly atmosphere. The researchers asked the children: "Let's *do a challenge! Can you follow these movements just like this little guy? Try to sit and then stand up, slowly and without the assistance of your arms or knees!"* Then, the researchers presented a short cartoon video with the correct actions of sitting and rising from the floor. The cartoon brought motivation and visual instruction.

After the SRT, researchers applied the cognitive test (PIPS), and the whole evaluation process lasted between 15 and 25 minutes. If requested, school staff members could stay in the same room as the children during assessments. The researchers' training process occurred for 2-3 days.

4.4 Study designs of analyses in chapters 5, 6 and 7

This thesis will provide analyses divided into three parts: the first focuses on the relationship between non-aerobic physical fitness and socioeconomic status. The second analyzes the relationship between non-aerobic physical fitness and cognitive development. The third seeks to understand the impact of attending preschool on the development of non-aerobic physical fitness. The three parts use distinct data and analytical models, with detailed discussion in each specific section. Table 4.2 summarizes the aims, designs, data sources, study populations, measures, and statistical methods of the three studies in the thesis.

Table 4.2: Overview of aims, designs, data sources, study populations, exposures/predictors, outcomes, and statistical methods used in chapters 5, 6 and 7

	Chapter 5	**Chapter 6**	**Chapter 7**
Aim	To examine the associations between socioeconomic status and non-aerobic physical fitness.	To examine the associations between non-aerobic physical fitness and cognitive development and the change of non-aerobic physical fitness and cognitive development.	To examine the effect of preschool attendance on non-aerobic physical fitness.
Design	Longitudinal	Longitudinal	Pre-post
Data source	The Longitudinal Study	The Longitudinal Study	The Longitudinal Study
Study population	children aged from 4 to 6 years	children aged from 4 to 6 years	children aged from 4.5 to 5 years
Exposures / predictors	SES	Non-aerobic physical fitness	Attending pre-school
Outcomes	Non-aerobic physical fitness	Cognitive development	Non-aerobic physical fitness
Confounders	Age Sex SEN Ponderal Index	Age Sex Ponderal Index SES SEN Baseline cognitive development	Age Sex SES
Statistical methods	Hierarchical Linear Models	Hierarchical Linear Models	Mann-Whitney U test

Note: SES= socioeconomic status; SEN= special educational needs

Chapter 5 describes the evolution of non-aerobic physical fitness performance of children over the two years of preschool. Next, it explores, with Hierarchical Linear Models[7] (HLM), factors associated with children's non-aerobic physical fitness with a particular interest in socioeconomic status.

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[7] Given that the units of analysis (school and child) are at different levels - children are grouped into schools - the HLM provides more advantages over conventional statistical methods to explain the school's social context influences on individuals.

Chapter 6 analyzes the relationship between cognitive development and children's non-aerobic physical fitness, considering the school and family context. Analyses will use HLM with two different approaches to investigate how non-aerobic physical fitness measures explain the differences in cognitive performance (Language and Mathematics measures). First, the baseline measure (Wave 1) of non-aerobic physical fitness will be set as the predictor of cognitive performance in waves 2 and 3. Second, analyses will estimate cognitive performance in waves two and three using the change of non-aerobic physical fitness over the first and second years of preschool as the main predictor.

Chapter 7 will use data relating to the first year of preschool, which had two waves of data collection, one at the beginning and one at the end of the school year. This analysis aims to identify whether preschool attendance affects the development of non-aerobic physical fitness in children. Therefore, it is essential to establish a research design with a group that attended preschool and another group that did not.

According to CNE/CEB[8] Resolution no. 6, October 20, 2010 (BRASIL, 2010b), to enroll in the first year of preschool, the child must be four years old by March 31 of the current year. For the second year of preschool, the age must be five years completed until the same cutoff date. This cutoff implies a wide age range within the same school year. On the other hand, in the context of a longitudinal study, it allows us to find children of a very similar age group at different time points.

In a preliminary analysis, we identified that in Waves 1 and 2, there is a group of children aged from four years and six months to five years (4.5 – 5 years). Therefore, it will be possible to analyze two groups (intervention= Wave 2 / control= Wave 1), theoretically equivalent, which differ depending on whether they have attended preschool or not.

4.5 Effect sizes

An increasing number of studies in educational research report their results in terms of effect size, and there is an extensive debate on the best forms of interpretation (HIGGINS et al., 2016). This thesis presents effect sizes with two similar approaches. For

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[8] CNE – *Conselho Nacional de Educação* (National Council of Education); CEB - *Câmara de Educação Básica* (Basic Education Chamber)

the results of HLM, the effect size calculation will use the approach suggested by Tymms[9] (2004). On the other hand, to report the difference between the two groups for the Mann-Whitney U test results in chapter 7, Cohen's d effect sizes will be presented.

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[9] This approach for calculating effect sizes in hierarchical linear models is similar to Cohen's *d* and Hedge's *g*.

5 THE RELATIONSHIP BETWEEN SOCIOECONOMIC STATUS AND NON-AEROBIC PHYSICAL FITNESS IN CHILDREN

5.1 Introduction

This chapter describes the non-aerobic physical fitness performance of preschool children throughout Brazil's first two years of compulsory education. In addition, it explores associations between non-aerobic physical fitness and contextual characteristics of children and their families, with a particular interest in socioeconomic status (SES). The relevance of this information is due to the earlier mentioned health benefits associated with higher levels of physical fitness, physical activity, and exercise. In children, these benefits include better bone health, better weight status and, reduced risk for increases in weight and adiposity (JANSSEN; LEBLANC, 2010; PATE et al., 2019). Additionally, children presenting higher levels of physical fitness tend to be more physically active and are most likely to become physically active adults. (MALINA, 2001; PERKINS et al., 2004).

SES is a key variable in many research areas. For example, in educational research, for decades, SES presents a substantial positive relationship with children's academic performance (COLEMAN et al., 1966; JENCKS et al., 1972; KOSLINSKI; BARTHOLO, 2019; SIRIN, 2005). Moreover, SES is considered one of the strongest determinants of variations in health outcomes (CSDH, 2008). One possible way of observing SES effects on people's lives is through higher financial conditions that allow a wide range of opportunities and health-related behaviors. These opportunities and behaviors may include healthy nutrition (IRALA-ESTÉVEZ et al., 2000; VERMEIREN et al., 2018), access to urban green areas that are physically engaging (BOZKURT, 2021), less exposure to smoking (HUURRE; ARO; RAHKONEN, 2003; VERMEIREN et al., 2018), and sports participation (KAMPHUIS et al., 2008).

Previous studies presented in this thesis showed mixed results regarding the relationship between SES and physical fitness in children. Thus, in order to contribute to this body of knowledge, this chapter examines the associations between SES and non-aerobic physical fitness in preschool children.

5.2 Methods

5.2.1 Participants and study design

The longitudinal study provided the data used in this chapter. There was a probabilistic single-stage cluster sample stratified by characteristics of preschool provision and local authority of Rio de Janeiro's public municipal system. Children unable to participate in physical assessments were excluded from the analysis. However, those diagnosed with special educational needs (SEN), such as ADHD, Down syndrome, autism spectrum disorder, participated in the study and were included in the analysis.

5.2.2 Data analyses

The distribution of available data are presented as mean and standard deviation, median and interquartile range, or proportions. Bivariate relationships between all key variables were examined using Spearman’s correlations. To examine the relationship between SES and non-aerobic physical fitness, hierarchical linear regression models were estimated, using the SRT measures in the first, second, and third waves of the longitudinal study as dependent variables. The first step was to develop a null model to partition the variance for SRT into its within- and between-groups (level 1 = child, level 2= school) components. After that, the following independent variables (level 1) were included: SES index, sex, age, diagnose for learning disabilities (special educational needs) and Ponderal Index (individual level 1 variables). Table 5.1 presents a description of all variables included in the models.

Table 5.1: variables used in the hierarchical linear model.

Name	Type	Description
Dependent variables		
Sitting-Rising Test	Continuous	non-aerobic physical fitness measure in the beginning of first year of preschool
Independent variables		
Socio economic status (SES)	Continuous	Index with information about socioeconomic status, housing conditions, parental educational level, and poverty (access to cash transfer programs)
Age (years)	Continuous	Age at the data collection
Sex	Dummy	0= girl 1= boy
Special Educational Needs (SEN)	Dummy	Children diagnosed with learning problems or disabilities (ADHD, Down syndrome, autism spectrum disorder)
Ponderal index	Continuous	Height (cm) / $\sqrt[3]{\text{weight}}$ (kg)

5.3 Results

Table 5.2 presents descriptive statistics of children at the first wave of data collection.

Table 5.2: descriptive characteristics of the children (Wave 1).

	N	All (n=2706)	Girls (n=1342)	Boys (n=1342)
Age		4.53 (.34)	4.53 (.33)	4.52 (.35)
Ponderal Index		40.74 (2.03)	40.74 (2.06)	40.73 (1.99)
SEN		1.8% (n=50)	.9% (n=12)	2.8% (n=38)
SES		.30 (1.41)	.28 (1.40)	.31 (1.42)

Table 5.3 presents descriptive analyzes of the SRT over the two preschool years. In each year, only children with two measurements were included (Wave 1 and 2, for the first year; Waver 2 and 3 for the second year). For better visualization, Figure 5.1 and 5.2 illustrates the histograms of performance in the SRT for the same period.

Table 5.3: descriptive statistics of the SRT in the two years of preschool

	Mean (SD)	Median (P25-P75)	Mode
First year (n=2186)			
SRT – Wave 1	8.49 (1.44)	9 (7.5 – 10)	10
SRT – Wave 2	9.03 (1.26)	9.5 (8 – 10)	10
Second year (n=2315)			
SRT – Wave 2	9 (1.27)	9.5 (8.5 – 10)	10
SRT – Wave 3	9.20 (1.35)	10 (8.5 – 10)	10

Note: SD= standard deviation; P25= 25th percentile; P75= 75th percentile.

The SRT's scores are close to the maximum value of the scale (0 to 10) already in Wave 1 and tend to increase in the following data wave collections. Through visual inspection (Figures 5.1 and 5.2), it becomes clearer to observe a possible suggestion of ceiling effect in this age group.

Figure 5.1: Histogram of SRT performance in the first year of preschool

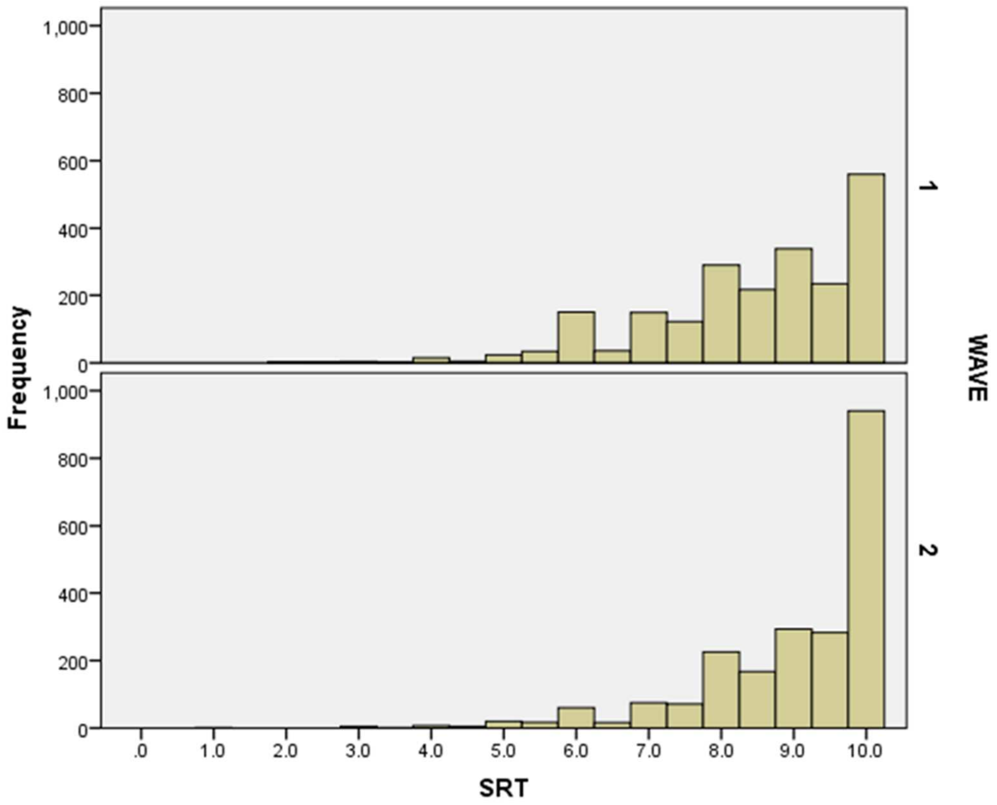


Figure 5.2: Histogram of SRT performance in the second year of preschool

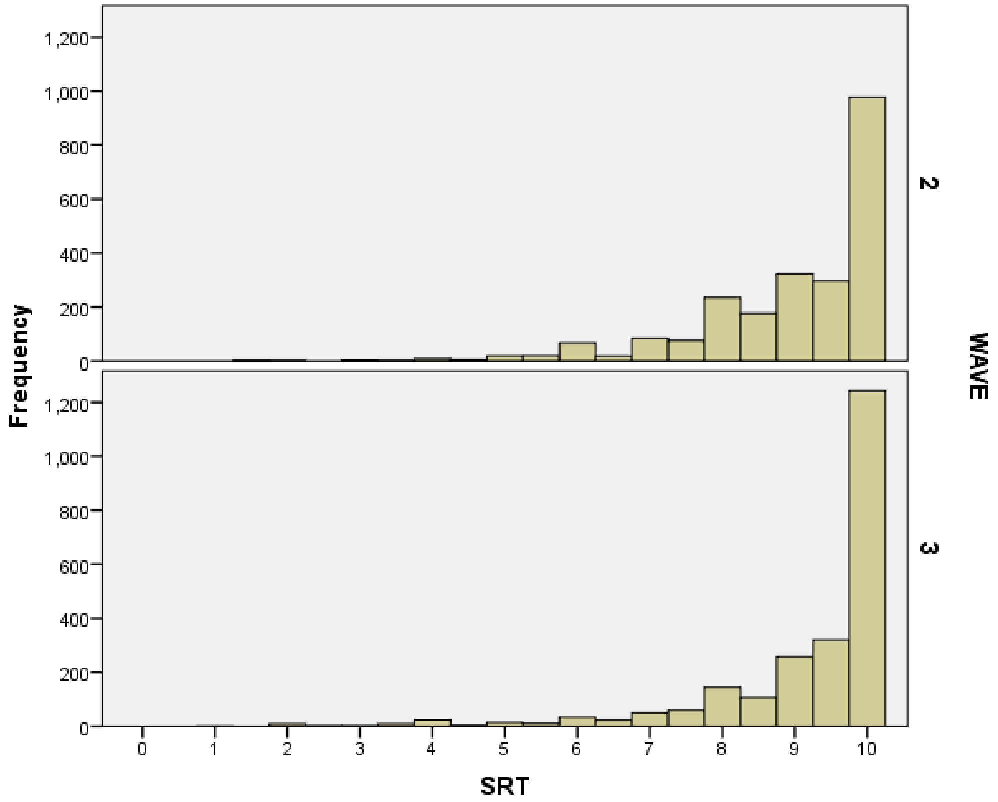


Table 5.4 presents the bivariate correlations between the SRT and the child's sociodemographic characteristics, considering each wave of data collection.

Table 5.4: Bivariate correlation between SRT, SES, age, Ponderal index, diagnosis for special educational needs, and sex in the three waves of data collection.

	SRT Wave 1	SRT Wave 2	SRT Wave 3
SES	-.01	-.01	-.01
AGE	**.20**	**.10**	**.05**
SEX	**-.13**	**-.15**	**-.09**
SEN	**-.11**	**-.12**	**-.12**
Ponderal Index	**.21**	---	---

Note: SES = Socioeconomic status; SRT = Sitting-Rising Test; SEN = Special Educational Needs. Significant correlation coefficients are in bold. $p<0.05$

The correlation between SES and SRT does not indicate a significant association at any time of data collection. In the Appendix section, Figure 9.1 explores this result, suggesting no difference in the distribution of SRT scores in any range (quartile of distribution) of SES.

Regarding age, it is important to consider that, given the age cut-off point for enrollment in preschool (4 years completed by March 31 of the current school year), there is an age variation between children that can reach up to 1 year of difference. Therefore, the correlation between age and SRT is positive and significant, indicating a relative effect of age (CUPEIRO et al., 2020) on SRT performance. Furthermore, this relationship remains significant over time, but with lower coefficients, possibly due to the previously mentioned SRT's ceiling effect. See Figures 9.2, 9.3, and 9.4 (appendix) for a visual inspection.

The negative correlation between SRT and sex (boy coded 1) indicates that girls, on average, show better performance on SRT. This relationship remains significant over time but with lower coefficients in each wave. Anthropometric height and body weight data were collected only in the first wave. The correlation between SRT and Ponderal index indicates that children with a better height/weight ratio had better results in the SRT. These results are in line with studies that investigated the influence of body composition on SRT performance in adults (RICARDO; ARAÚJO, 2001). In addition, children diagnosed with special educational needs presented a lower performance in the SRT.

To examine factors associated with non-aerobic physical fitness, Tables 5.5, 5.6, and 5.7 present the hierarchical linear regression models results. The outcome variable was the SRT performance at Wave 1, 2, and 3 (Tables 5.5, 5.6, and 5.7, respectively) and the explanatory variables SES, sex, age, diagnosis for special educational needs, and Ponderal Index. The effect sizes were calculated using the approach suggested by Tymms (2004).

Table 5.5: Hierarchical linear model estimating the SRT performance in Wave 1

	B (s.e.)	95% CI	p-value	Effect size
Sitting-Rising test				
SES	0.03 (0.03)	-0.04, 0.09	0.402	0.03
AGE	**0.25** (0.04)	0.18, 0.33	0.001	**0.28**
SEX	**-0.33** (0.07)	-0.46, -0.21	0.001	**-0.18**
SEN	**-1.20** (0.22)	-1.64, -0.76	0.001	**-0.66**
Ponderal Index	**0.32** (0.04)	0.25, 0.39	0.001	**0.35**
Explained Variance				
school	-59%			
child	29%			
ICC	0.03			
Null Model				
Var (school)	0.03			
Var (child)	2.07			
ICC	0.02			
N	1733			

Note: B= unstandardized coefficients; s.e.= standard error; CI= confidence interval; SES = Socioeconomic status; SEX= boy (coded 1); SEN = Special Educational Needs. Significant correlation coefficients are in bold. p<0.05

Table 5.6: Hierarchical linear model estimating the SRT performance in Wave 2

	B (s.e.)	95% CI	p-value	Effect size
Sitting-Rising test				
SES	0.00 (0.03)	-0.06, 0.05	0.889	0.00
AGE	**0.12** (0.03)	0.06, 0.19	0.001	**0.08**
SEX	**-0.27** (0.06)	-0.38, -0.16	0.001	**-0.18**
SEN	**-0.87** (0.17)	-1.20, -0.53	0.001	**-0.57**
Explained Variance				
school	-4%			
child	1%			
ICC	0.03			
Null Model				
Var (school)	0.04			
Var (child)	1.56			
ICC	0.03			
N	2007			

Note: B= unstandardized coefficients; s.e.= standard error; CI= confidence interval; SES = Socioeconomic status; SEX= boy (coded 1); SEN = Special Educational Needs. Significant correlation coefficients are in bold. $p<0.05$

Table 5.7: Hierarchical linear model estimating the SRT performance in Wave 3

	B (s.e.)	95% CI	p-value	Effect size
Sitting-Rising test				
SES	0.00 (0.03)	-0.06, 0.06	0.959	0.00
AGE	0.05 (0.03)	-0.01, 0.12	0.128	0.03
SEX	**-0.18** (0.06)	-0.30, -0.07	0.002	**-0.11**
SEN	**-1.54** (0.19)	-1.92, -1.17	0.001	**-0.93**
Explained Variance				
school	3%			
child	1%			
ICC	0.07			
Null Model				
Var (school)	0.12			
Var (child)	1.68			
ICC	0.07			
N	1956			

Note: B= unstandardized coefficients; s.e.= standard error; CI= confidence interval; SES = Socioeconomic status; SEX= boy (coded 1); SEN = Special Educational Needs. Significant correlation coefficients are in bold. p<0.05

In the first wave of data collection (Table 5.5), the results of the hierarchical linear model indicate that only 2% (ICC=0.02) of the variance is explained by the school level, suggesting that the major differences in SRT performance are explained in the level 1. Following the results presented in Table 4 (bivariate correlations), the coefficients did not suggest an association between the SES and SRT performance. However, the other variables in the model remain significant with small to moderate effect sizes.

The results for the Wave 2 and 3 (Table 5.6 and 5.7, respectively) are similar to the previous model, not suggesting an association between SES and SRT. Furthermore, sex, age, and SEN presented significant results with smaller effect sizes. Interestingly, the increase in the intraclass correlation at Wave 2 and 3 (ICC= 0.04, 0.07, respectively) suggests that a small but higher proportion of variance is explained at the school level (level 2).

5.4 Discussion

This chapter aimed to describe the performance of preschool children in their non-aerobic physical fitness during the first two years of compulsory education. For this, the assessments used the Sitting-Rising test, a simple and reliable screening tool that evaluates rudimentary motor skills (sitting and rising from the floor) learned very early in life (GALLAHUE; OZMUN; GOODWAY, 2019; SHIRLEY, 1931). The results suggest a ceiling effect for children in this age group since most could perform the motor tasks perfectly. Moreover, this trend became more noticeable over time. Nonetheless, some children do not achieve the "10" perfect score in the SRT, which may indicate some negative aspects regarding children's non-aerobic physical fitness, such as low muscle strength and flexibility, poor balance and motor coordination, overweight, or maybe a combination of these factors.

Another aim of the chapter was to explore the relationship between preschoolers' non-aerobic physical fitness and contextual factors such as the families' socioeconomic status, age, sex, body composition, and learning disabilities. No associations were found in the bivariate correlation or the hierarchical linear models regarding the relationship between SES and SRT. We must look carefully at this result since the literature review presented in Chapter 2 indicates mixed results regarding the SES-fitness relationship in children and adolescents. For example, Sandercock et al. (2017) found that non-aerobic physical fitness was associated with the regional indicator of SES in Colombian adolescents (14-16-year-old). Still, Otero et al. (2017) found results in the opposite direction. Their Colombian sample of children had a slightly wide age range (8-17-year-old), which could have affected the results. As indicated in two other studies, the association between SES and physical fitness measures varies by age. First, in the longitudinal study by Freitas et al. (2007), no association was found between SES groups and physical fitness in the younger cohort (7-9 years old), except for hand-eye coordination and aerobic fitness. Second, Vermeiren et al. (2018) has indicated that SES differences in handgrip strength and aerobic fitness were larger in older than in younger children (with no significant differences in the 4-6-year-old age group). This lower (or lack of) association in young children could partially explain this chapter's results.

In addition, we hypothesized that families with higher financial conditions that live in a structured environment (high SES) could provide better opportunities for developing their children’s non-aerobic physical fitness. Although the SES index used in the analyses was a comprehensive measure comprising several aspects of the contextual characteristics of the families, we cannot rule out the possibility that none of this information adequately captured opportunities or factors related to the development of physical fitness. The Physical Activity Guidelines for the Brazilian Population (*Guia de Atividade Física para a População Brasileira*) (BRASIL, 2021) proposes four domains where physical activity can occur: at home, at leisure, at school, and commuting. Possibly, since physical activity and physical fitness are mutually related (STODDEN et al., 2008), an SES measure or index incorporating those physical activity domains could more accurately assess aspects related to physical fitness performance.

Finally, the analysis of this chapter used data from a longitudinal study comprising a sample of children from the public school system of one Brazilian municipality. Since a higher proportion of children from low socioeconomic status attend public schools in Brazil's educational system, our sample might be considered homogeneous concerning the families' SES, not allowing us to observe a relationship between SES and non-aerobic physical fitness.

5.5 Conclusion

This chapter's findings indicate that the families' socioeconomic status is not associated with the children's non-aerobic physical fitness in the first two preschool years. Future studies should assess the SES incorporating information that captures families' routines and factors related to the development of physical fitness. In addition, these studies should include data from the private and public school system, attempting to analyze the relationship between SES and physical fitness with a more heterogeneous sample regarding the socioeconomic profile of families.

6 RELATIONSHIPS BETWEEN NON-AEROBIC PHYSICAL FITNESS AND COGNITIVE DEVELOPMENT

6.1 Non-aerobic physical fitness as a predictor of cognitive development

Early childhood is the most critical and rapid period of healthy motor and cognitive development in human life (UNICEF, 2017). Furthermore, increased stimulation by physical activity or intervention programs may provide health benefits across childhood and adolescence (ZENG et al., 2017). Thus, a more comprehensive understanding of the relationship between cognition and aspects of motor development can offer relevant information for the design of public policies in education. This chapter aims to analyze the longitudinal relationship between non-aerobic physical fitness and future cognitive performance in language and mathematics of preschool children.

6.1.1 Participants and study design

The data used in the chapter is part of a longitudinal study (described on Chapter 4) undertaken in the city of Rio de Janeiro, Brazil. The study presents a probabilistic single-stage cluster sample (school as the primary sampling unit) stratified by characteristics of preschool provision and local authority of the public municipal system. The study considered all the children enrolled in the first year of preschool (first year of compulsory education in the Brazilian educational system), of 46 public schools in the year 2017, as eligible to participate in the study. Children with visual and hearing impairment or inability to participate in physical assessments were excluded from the analysis. Those diagnosed with special educational needs, such as ADHD, Down syndrome, autism spectrum disorder, participated in the study and were included in the analysis.

A total of three waves of data collection for the cognitive and non-aerobic physical fitness were conducted: a) 1st wave at the beginning of the first year in school (March/April 2017); b) 2nd wave at the end of the first year in school (November/December 2017); c) 3rd wave at the end of the second year in school (November/December 2018). For this study, only those children who provided data on both cognitive and non-aerobic physical fitness measurements at baseline and follow-up were included. A total of 1,380 children provided data for baseline and 2nd wave whereas for baseline and 3rd wave, 1,320 children.

6.1.2 Data analyses

For descriptive statistics, data are presented as mean and standard deviation or proportions. Bivariate relationships between all key variables were examined using Spearman's correlations. To assess the longitudinal relationship between non-aerobic physical fitness and cognitive development, hierarchical linear regression models were estimated, using the cognitive measures in the 2nd and 3rd waves of the longitudinal study as outcome variables and the non-aerobic physical fitness measure as a predictor, adjusting for confounding variables (including baseline cognitive development measures). The use of the PIPS baseline cognitive measures as covariate intend to account for pre-existing differences in children's cognitive development (academic performance). This approach (use of pre-test as covariate) reduces Type II errors despite the risk of less effective bias reduction in parameter estimates (CRONBACH; FURBY, 1970; HOWES et al., 2008). Nevertheless, there are many longitudinal studies in the physical fitness-cognition research that used this approach (HAAPALA et al., 2019; MCLOUGHLIN; BAI; WELK, 2020; NIEDERER et al., 2011; SARDINHA et al., 2016; SON; MEISELS, 2006). Measured confounding variables (age, sex, SES, learning disabilities, body composition) were selected based in previous research examining the relationship between physical fitness and cognition in children and from recommendations in systematic reviews (DONNELLY et al., 2016; FEDEWA; AHN, 2011; RUIZ-ARIZA et al., 2017). The analyses were made using SPSS version 23. All testing was two-tailed and at a significance level of 5% of probability. Table 6.1 presents a description of all variables included in the models.

Table 6.1: variables used in the hierarchical linear models

Name	**Type**	**Description**
Dependent variables		
Language 2nd Wave	Continuous	Language measurement at the end of first year of preschool
Language 3rd Wave	Continuous	Language measurement at the end of second year of preschool
Mathematics 2nd Wave	Continuous	Mathematics measurement at the end of first year of preschool
Mathematics 3rd Wave	Continuous	Mathematics measurement at the end of second year of preschool
Independent variables		
Language baseline (1st Wave)	Continuous	Language measurement at the beginning of first year of preschool
Mathematics baseline (1st Wave)	Continuous	Mathematics measurement at the beginning of first year of preschool
Sex	Dummy	0= girl 1= boy
Age (years)	Continuous	Age at the data collection
Sitting-Rising Test	Continuous	non-aerobic physical fitness measure in the beginning of first year of preschool
Socio economic status (SES)	Continuous	Index with information about socioeconomic status, housing conditions, parental educational level, and poverty (access to cash transfer programs)
Special Educational Needs (SEN)	Dummy	Children diagnosed with learning problems or disabilities (ADHD, Down syndrome, autism spectrum disorder)
Ponderal index	Continuous	Height (cm) / $\sqrt[3]{\text{weight (kg)}}$

6.1.3 Results

Table 6.2 shows the descriptive statistics of the participants in each time point of data collection. Waves 1 and 2 refer to the first year of preschool having seven months of time difference. However, Wave 3 (referring to the second year) shows a 12-month difference regarding Wave 2. The performance of preschool children in the SRT indicates that most of them achieved high scores. Indeed, the most frequent score was the perfect "10". This result became more visible over time, which indicates a ceiling effect for this age group.

Table 6.2: Descriptive statistics of the participants

	1st Wave	2nd Wave	3rd Wave
Age *	4.41 (0.36)	5.08 (0.36)	6.08 (0.36)
Sex (boy) †	52.9%	53.2%	52.1%
Ponderal index *	40.74 (2.02)	-	-
SES *	0.30 (1.41)	0.29 (1.46)	0.25 (1.43)
SEN †	2,1%	2,8%	2,2%
SRT *	8.48 (1.44)	8.98 (1.30)	9.14 (1.40)
PIPS			
Language *	-0.28 (0.96)	0.27 (0.89)	0.92 (0.98)
Mathematics *	-2.79 (1.33)	-1.85 (1.39)	-0.59 (1.56)

Note: SES = Socio economic status; SEN = Special Educational Needs; PIPS = Performance Indicator for Primary Schools; SRT = Sitting-Rising Test *mean (SD) †proportions

Correlations between all key variables in the first wave of data collection are presented in Table 6.3. The SRT was weakly correlated with statistically significant coefficients with all measurements except SES. Performance in both cognitive tests was positively associated with the SRT. Older children showed better performance in SRT as well as those with higher values of Ponderal Index (indicating a better height/weight relationship). Sex (coded boy = 1) presents a negative correlation with SRT, indicating that girls outperformed boys in this task. Children diagnosed with SEN showed worse performance in SRT.

Table 6.3: Bivariate correlations between all key variables (1st Wave)

	1.	2.	3.	4.	5.	6.	7.	8.
1. SRT	-	**.25**	**.17**	**.19**	**.23**	**-.15**	-.01	**-.10**
2. Language		-	**.58**	**.28**	.02	**-.10**	**.25**	**-.08**
3. Mathematics			-	**.27**	.01	-.04	**.24**	.01
4. Age				-	**.21**	-.02	-.02	-.01
5. Ponderal Index					-	-.01	-.05	.02
6. Sex (boy)						-	.03	**.06**
7. SES							-	**.05**
8. SEN								-

Note: SES = Socio economic status; SRT = Sitting-Rising Test; SEN = Special Educational Needs. Significant correlation coefficients are in bold. p<0.05

To further investigate the relationship between non-aerobic physical fitness and cognitive performance, Figures 6.1 and 6.2 plots the measures of Mathematics and Language against SRT scores at Wave 1 (information regarding Waves 2 and 3 are available in the Appendix section – Figures 10.1, 10.2, 10.3, and 10.4).

Figure 6.1: Boxplot with SRT and Mathematic performance - Wave 1

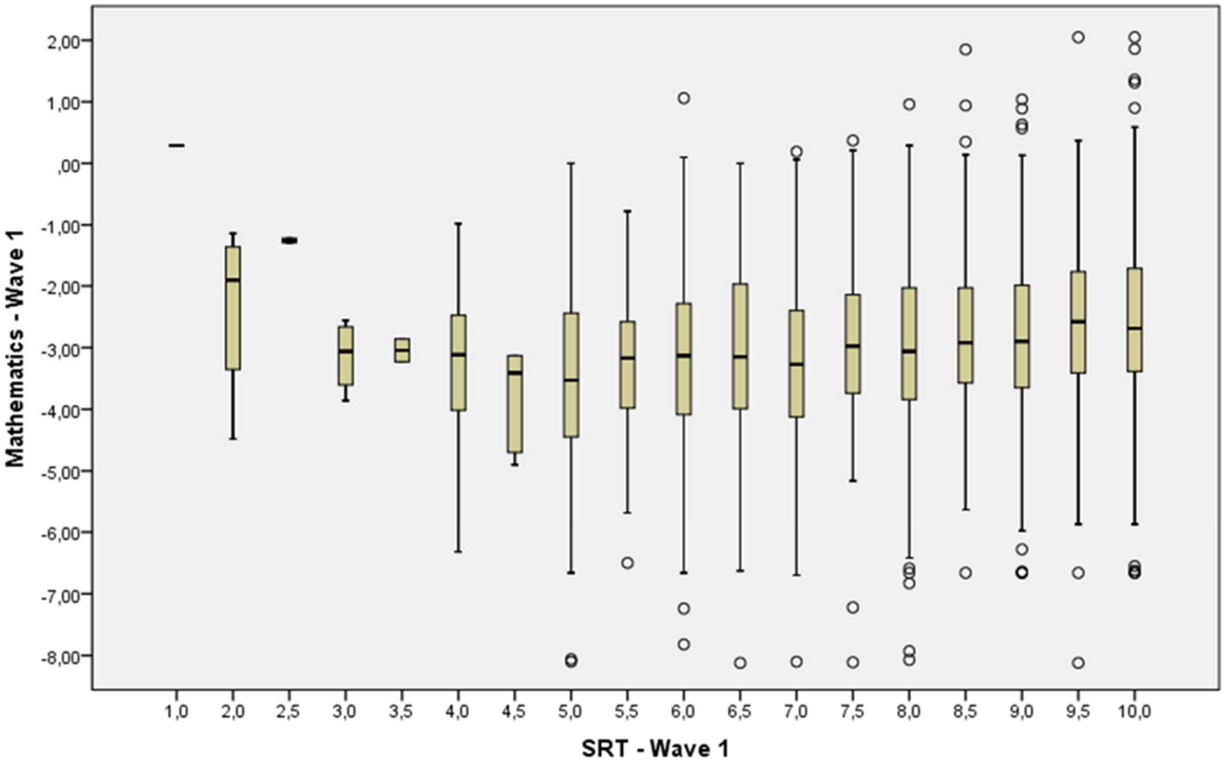
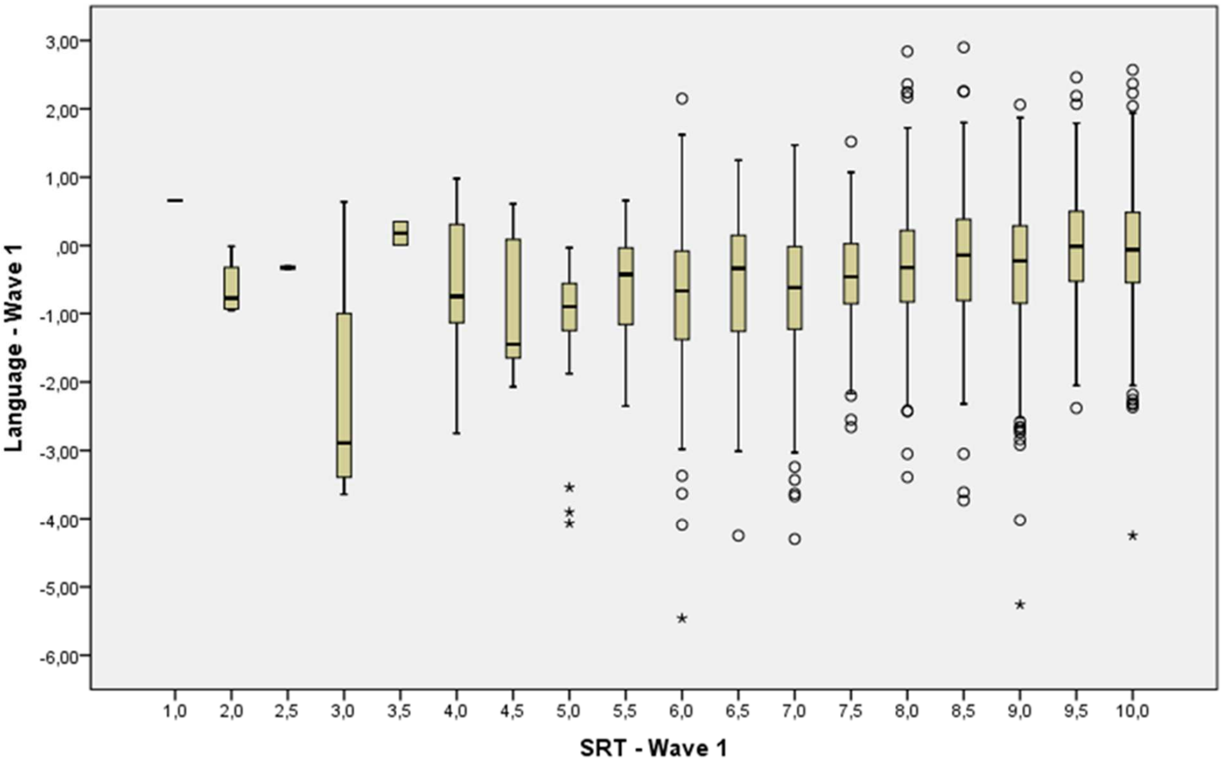


Figure 6.2: Boxplot with SRT and Language performance - Wave 1



Figures 6.1 and 6.2 illustrate a slightly positive association between the SRT scale and PIPS scores at the beginning of preschool's first year. The boxplots present a wide range of cognitive performance for each SRT score. In fact, some children with a perfect "10" score in the SRT presented an inferior performance in both cognitive tests. Figures 10.1, 10.2, 10.3, and 10.4 (appendix) show a similar trend for this relationship. In addition, children with SRT's higher scores had a slightly more pronounced difference in the median scores of Mathematics and Language.

Tables 6.4, 6.5 (first year of preschool), 6.6, and 6.7 (second year of preschool) presents the four-step hierarchical regression analyses[10] that were performed for language and mathematics performance as dependent variables to examine the relationship of non-aerobic physical fitness measure after controlling for potential confounders (baseline cognitive measures, sex, age, body composition and socioeconomic status). After that, effect sizes for the coefficients of the SRT were calculated using the approach suggested

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[10] Figures for each independent variable are presented as unstandardized coefficients and standard errors.

by Tymms (2004). Since the SRT was considered a continuous variable in the model, the formula for the calculation is:

$$ES = \frac{2 * \beta 1 * \mathrm{SDpredictor}}{\sigma \mathrm{e}}$$

Where:

β_1 is the SRT coefficient

$SD_{predictor}$ is the standard deviation of the SRT

σ_e is standard deviation at child level in the null model

A four-step modeling approach was used to examine the unique influence of the Sitting-Rising Test on cognitive development and progressively adjust for confounders. First, the demographic variables were entered in Model 1 (sex, age, diagnose of special educational needs, and socioeconomic status). Then, children's baseline cognitive measure was entered (Model 2). Next, model 3 added the SES at the school level. At last, in Model 4, the Ponderal index (body composition) was included. To understand the impact of the considerable reduction of cases due to the use of the Ponderal Index in Model 4, an additional model, identical to Model 3, was estimated but only using those that had body composition measures (Model 3.1).

Table 6.4: Hierarchical linear regression models estimating 2nd Wave mathematics measurements (first year of preschool)

	Model 1	Model 2	Model 3	Model 3.1	Model 4
Mathematics					
SRT	**0.12** (0.02)	**0.05** (0.02)	**0.05** (0.02)	**0.05** (0.02)	**0.04** (0.02)
SEX	0.05 (0.06)	0.08 (0.04)	0.08 (0.04)	0.08 (0.05)	0.08 (0.05)
AGE	**0.42** (0.04)	**0.11** (0.03)	**0.11** (0.03)	**0.12** (0.03)	**0.12** (0.03)
SES	**0.33** (0.03)	**0.11** (0.02)	**0.11** (0.02)	**0.11** (0.02)	**0.12** (0.02)
SEN	-0.46 (0.27)	-0.33 (0.19)	-0.34 (0.19)	-0.31 (0.21)	-0.33 (0.21)
Mathematics (baseline)		**0.97** (0.02)	**0.97** (0.02)	**0.96** (0.03)	**0.96** (0.03)
Ponderal Index					0.05 (0.03)
SES (school)			0.03 (0.03)	0.01 (0.03)	0.01 (0.03)
Explained Variance					
school	40%	67%	66%	86%	86%
child	17%	57%	58%	57%	57%
ICC	0.04	0.04	0.04	0.02	0.02
Null Model					
Var (school)	0.10				
Var (child)	1.78				
ICC	0.05				
N	1670	1670	1670	1380	1380

Note: SES = Socio economic status; ICC = intraclass correlation coefficient; SRT = Sitting-Rising Test; SEN = Special Educational Needs. Significant correlation coefficients are in bold. $p<0.05$

In the first year of preschool (estimating 2nd wave cognitive measures) significant associations were found between SRT and Mathematics even after controlling for contextual variables in Model 1 (ES=0.23). The inclusion of baseline mathematics scores in Model 2 explained additional variance in relation to the null model (67% at school level; 53% at child level), and the effect size for SRT reduced slightly (0.20). Entering the SES at the school level (Model 3) did not change the model, and when all predictors were added, Model 4 explained 86% of the variance at the school level and 57% at the child level. Results indicate that every additional point in the SRT at the beginning of preschool had an effect size of 0.16 in mathematics scores at the end of the year after controlling for baseline cognitive measure, sex, age, body composition, diagnose of special educational needs and socioeconomic status. The analysis of Model 3.1 shows that the reduction of cases did not have a substantial impact on the results.

Table 6.5: Hierarchical linear regression models estimating 2nd Wave language measurements (first year of preschool)

	Model 1	Model 2	Model 3	Model 3.1	Model 4
Language					
SRT	**0.07** (0.01)	0.00 (0.01)	0.00 (0.01)	-0.01 (0.01)	-0.01 (0.01)
SEX	**-0.09** (0.04)	-0.01 (0.03)	-0.01 (0.03)	0.00 (0.03)	0.00 (0.03)
AGE	**0.26** (0.02)	**0.08** (0.02)	**0.09** (0.02)	**0.09** (0.02)	**0.08** (0.02)
SES	**0.19** (0.02)	**0.06** (0.01)	**0.06** (0.01)	**0.05** (0.02)	**0.05** (0.02)
SEN	**-0.76** (0.16)	**-0.25** (0.12)	**-0.26** (0.12)	**-0.36** (0.14)	**-0.36** (0.14)
Language (baseline)		**0.55** (0.02)	**0.55** (0.02)	**0.55** (0.02)	**0.56** (0.02)
Ponderal Index					0.02 (0.02)
SES (school)			**0.04** (0.02)	0.02 (0.02)	0.02 (0.02)
Explained Variance					
school	44%	70%	73%	76%	76%
child	20%	53%	53%	52%	52%
ICC	0.04	0.04	0.04	0.03	0.03
Null Model					
Var (school)	0.04				
Var (child)	0.67				
ICC	0.06				
N	1670	1670	1670	1380	1380

Note: SES = Socio economic status; ICC = intraclass correlation coefficient; SRT = Sitting-Rising Test; SEN = Special Educational Needs. Significant correlation coefficients are in bold. $p<0.05$

For language scores, the association with SRT were significant only in Model 1 presenting an effect size of 0.38. In the subsequent models, the non-aerobic physical fitness measurement loses statistical significance, and the effect size values are negligible.

Table 6.6: Hierarchical linear regression models estimating 3rd Wave mathematics measurements (second year of preschool)

	Model 1	Model 2	Model 3	Model 3.1	Model 4
Mathematics					
SRT	**0.12** (0.02)	**0.06** (0.02)	**0.06** (0.02)	**0.06** (0.02)	**0.05** (0.02)
SEX	**0.17** (0.07)	**0.21** (0.06)	**0.21** (0.06)	**0.17** (0.06)	0.17 (0.06)
AGE	**0.42** (0.04)	**0.15** (0.04)	**0.15** (0.04)	**0.16** (0.04)	**0.16** (0.04)
SES	**0.32** (0.03)	**0.13** (0.03)	**0.12** (0.03)	**0.11** (0.03)	**0.11** (0.03)
SEN	**-1.48** (0.31)	**-1.30** (0.25)	**-1.31** (0.25)	**-1.26** (0.28)	**-1.28** (0.28)
Mathematics (baseline)		**0.87** (0.03)	**0.87** (0.03)	**0.86** (0.04)	**0.86** (0.04)
Ponderal Index					0.06 (0.03)
SES (school)			0.06 (0.03)	0.07 (0.04)	0.07 (0.04)
Explained Variance					
school	50%	68%	71%	79%	79%
child	19%	45%	45%	43%	43%
ICC	0.04	0.04	0.03	0.02	0.02
Null Model					
Var (school)	0.15				
Var (child)	2.29				
ICC	0.06				
N	1603	1603	1603	1320	1320

Note: SES = Socio economic status; ICC = intraclass correlation coefficient; SRT = Sitting-Rising Test; SEN = Special Educational Needs. Significant correlation coefficients are in bold. $p<0.05$

The longitudinal analyzes of the second year of preschool were conducted with the same procedures and presented similar results. Regarding the association of the SRT and mathematic scores, coefficients in Model 1 shows an ES= 0.19. Adding baseline mathematics scores, Model 2 increased the explained variance (68% at school level; 45% at child level) and SRT reduces its effect size (0.13). Model 3 shows insignificant changes and with Model 4 the explained variance was 79% and 43% at school and child level, respectively. Although slightly less than the end of the first year of preschool, the increase of each additional point on the SRT scale remains significant with an effect size of 0.11.

Table 6.7: Hierarchical linear regression models estimating 3rd Wave language measurements (second year of preschool)

	Model 1	Model 2	Model 3	Model 3.1	Model 4
Language					
SRT	**0.07** (0.01)	0.00 (0.01)	0.00 (0.01)	0.00 (0.01)	0.00 (0.01)
SEX	**-0.14** (0.04)	-0.05 (0.03)	-0.05 (0.03)	-0.06 (0.04)	-0.06 (0.04)
AGE	**0.24** (0.02)	**0.09** (0.02)	**0.09** (0.02)	**0.09** (0.02)	**0.09** (0.02)
SES	**0.21** (0.02)	**0.09** (0.02)	**0.09** (0.02)	**0.08** (0.02)	**0.08** (0.02)
SEN	**-0.95** (0.18)	**-0.41** (0.15)	**-0.42** (0.15)	**-0.41** (0.16)	**-0.41** (0.16)
Language (baseline)		**0.53** (0.02)	**0.53** (0.02)	**0.52** (0.02)	**0.52** (0.02)
Ponderal Index					0.01 (0.02)
SES (school)			**0.06** (0.02)	0.05 (0.03)	0.05 (0.03)
Explained Variance					
school	43%	52%	57%	56%	56%
child	27%	51%	51%	51%	51%
ICC	0.08	0.10	0.09	0.09	0.09
Null Model					
Var (school)	0.10				
Var (child)	0.86				
ICC	0.10				
N	1603	1603	1603	1320	1320

Note: SES = Socio economic status; ICC = intraclass correlation coefficient; SRT = Sitting-Rising Test; SEN = Special Educational Needs. Significant correlation coefficients are in bold. $p<0.05$

In the association of SRT and language, we found the same trend: a moderate effect size (0.32) in Model 1 and after that negligible effect sizes with no statistical significance.

6.1.4 Discussion

This chapter aimed to quantify the longitudinal link between non-aerobic physical fitness and cognitive development in a large sample of preschool children. The bivariate correlations suggest a significant but weak association of the SRT with both cognitive measurements. In the hierarchical linear models, the baseline measurements of the SRT were related to some improvements in cognitive parameters depending on the academic domain involved. In language, the relationship of non-aerobic physical fitness measurements did not remain significant after adjustment for covariates, in the first and second years of preschool. On the other hand, the SRT was related to mathematics performance after controlling for confounding variables. The increase of one point in the SRT scale at the start of compulsory education represented an effect sizes of 0.16 and 0.11 at the end of the first and second year of preschool, respectively The small magnitude of the coefficients found in our study is similar to previous studies (AADLAND et al., 2017; VAN DUSEN et al., 2011), but there are two reasons to believe that what we have reported is more important than the small effect sizes imply. The first is that the SRT could only pick out children with difficulties since most could easily complete the task perfectly. A non-aerobic physical fitness test that discriminated across the full range may have revealed a stronger association. Secondly, the effect sizes were for one point on the SRT, and the sample includes some cases that had scored 2.5 below the 10's perfect score. That corresponds to effect sizes of 0.40 and 0.27 respectively for the two waves and represents four to five months of learning progress (HIGGINS et al., 2016).

The SRT is a screening test that assesses, through simple motor tasks, at least four components of non-aerobic physical fitness, namely muscle strength/power, flexibility, balance, and body composition. SRT has been used to measure non-aerobic physical fitness in several different populations and middle-aged and older subjects. The results suggest that the SRT is a good predictor of all-cause mortality (BRITO et al., 2014). Additionally, Ventista (2015) found a moderate association between the SRT and MABC-2 (Movement Assessment Battery for Children- 2nd edition) in preschool children. Recently, age- and sex-reference scores were made available for a sample of 6,141 adults

(ARAÚJO et al., 2020). The possibility of a ceiling effect in young children is expected (ARAÚJO, 1999) and was also found in this chapter's analyses. The results corroborates the claim that performing the actions of sitting and rising from the floor is simple and could be considered fundamental human skills (GREEN; WILLIAMS, 1992) learned very early in life (GALLAHUE; OZMUN; GOODWAY, 2019). But, more importantly, the inability to perform these actions, when measured by the SRT, may indicate some adverse changes in the components of non-aerobic physical fitness. For example, overweight, low flexibility, poor balance, low muscle strength/power, poor motor coordination, or, quite often, some combination of these.

Other studies, however, have not observed statistically significant associations between non-aerobic physical fitness components (musculoskeletal fitness) and academic achievement (CASTELLI et al., 2007; TORRIJOS-NIÑO et al., 2014). Further, the finding that non-aerobic physical fitness components were associated with math scores but not on language is consistent with some previous studies (AADLAND et al., 2017; EVELAND-SAYERS et al., 2009). Whilst others studies, however, had found that this relationship occurred in both academic domains (DE BRUIJN et al., 2019; ESTEBAN-CORNEJO et al., 2014b; HAAPALA et al., 2014).

These mixed results could be explained by the different analytical approaches across studies, different measurements and inconsistency in controlling for potentially confounding variables (KAO et al., 2017). Additionally, problems can arise when academic decisions are made according to statistical significance; it is confounded with sample size which had a high range across the studies.

The results reported in this chapter were based on large sample sizes with outcomes at two points in time separate by a year. Results suggest a link between non-aerobic physical fitness and mathematics but not with language for young children. Any explanation of the link must therefore discriminate between language and mathematics.

The previous explanation includes: a) during several motor and cognitive tasks brain regions namely the prefrontal cortex, the cerebellum, and the basal ganglia show co-activity (DIAMOND, 2000); b) these skills might have a similar developmental timetable with an accelerated maturation during early and middle childhood (ANDERSON et al., 2001; VAN DER FELS et al., 2014); c) both motor and cognitive skills have several common underlying processes, such as sequencing, monitoring, and planning (ROEBERS; KAUER, 2009); d) motor skills training induces brain plasticity through increases in brain-derived neurotrophic factor levels and tyrosine kinase receptors, synaptogenesis and motor map reorganization in the motor cortex (ADKINS et al., 2006); d) muscular fitness may affect cognition through the production of cognition-related neurochemicals like growth factor 1 (IGF- 1) (CASSILHAS et al., 2007) and brain-derived neurotrophic factor (BDNF) expression (LEE et al., 2012; SUIJO et al., 2013). A further suggestion involves a mediation process by executive functions as a possible mechanism (ALLOWAY; ARCHIBALD, 2008; ROEBERS et al., 2014).

But, whilst each explanation may have some merit, none discriminates between language and mathematics and, a full explanation is beyond the scope of this chapter. One possibility is that the link between arithmetical concepts and finger counting is fundamental (ANDRES; DI LUCA; PESENTI, 2008) and that this provides the link between physical development and mathematics but not language. Further empirical work would be needed to explore this in more detail.

The strength of the present analyses is partly that it was based on a large sample size of children at the beginning of the first year of compulsory education in Brazil. Also, the longitudinal design allows analyzing the relationship between non-aerobic physical fitness and academic performance at various time points. The non-aerobic physical fitness components were assessed with the Sitting-Rising Test, a well-known and objective assessment tool that is easily administered and provides a reliable measure (LIRA; ARAÚJO, 2000). The cognitive assessment is based on skills and domains of knowledge that research has shown to be the best predictors of later success at school (TYMMS, 1999). This chapter has also some limitations. SRT presents a celling effect for this age group, therefore, we may have lost some discriminative power among those with a score of 10. In addition, it was only feasible to collect data of height and weight (Ponderal Index) in the 1st Wave.

6.1.5 Conclusion

This chapter's findings indicate that non-aerobic physical fitness is associated with the cognitive development of preschool children (ages 4 and 5). Future studies should investigate how the development of non-aerobic physical fitness components across childhood relates to cognitive development and, more importantly, if controlled interventions (RCTs) focused on non-aerobic physical fitness components could increase cognition in children. Moreover, future studies should seek to better understand the mechanisms of the physical fitness-cognition relationship specifically using executive function measurements as a mediation process. Our findings, along with other studies (DE BRUIJN et al., 2019; ESTEBAN-CORNEJO et al., 2014b; NIEDERER et al., 2011) suggest that the non-aerobic physical fitness components could contribute to a child's cognitive development in addition to other health-related benefits. This message should encourage educational policymakers to translate this finding and assure opportunities for healthy development and lifestyle for preschool-aged children.

6.2 Changes in non-aerobic physical fitness and cognitive development

In the previous section (6.1), the relationship between non-aerobic physical fitness and cognitive development were explored using initial SRT measures (Wave 1) as a predictor of prospective performance in mathematics and language (Waves 2 and 3). This section aims to analyze the relationship between changes in non-aerobic physical fitness and cognitive development over the 1st and 2nd years of preschool.

Studies that analyzed changes in physical fitness components and their relationship with academic or cognitive performance in children are scarce in the literature. A longitudinal study of 1,286 students from 14 public schools in Portugal showed that adolescents (11 to 14 years of age) who improved their aerobic fitness or maintained a healthy aerobic fitness zone for three years had significantly better results in language, but not in mathematics skills (SARDINHA et al., 2016). Syväoja et al. (2019) examined longitudinal associations between aerobic and non-aerobic components of physical fitness, motor skills, and academic performance in 954 children and adolescents (9-15 years) in a 2-year study (3 waves of data collection). Changes in aerobic and musculoskeletal fitness were positively associated with changes in academic performance (β=0,27, [$IC_{99\%}$=0,06-0,48]; β=0,36, [$IC_{99\%}$=0,11-0,63]) while changes in motor skills were not related to changes in academic performance. On the other hand, higher levels of motor skills (Wave 2) proved to be predictors of academic performance one year later (Wave 3) (β= 0.06, [$IC_{99\%}$= 0,00–0,11]; β = 0.06, [$IC_{99\%}$= 0,01–0,11]) while the components of physical fitness were not shown to be predictors of academic performance.

Similarly, a longitudinal study with 1,802 children aged 10 to 12 years examined the association between motor skills, components of physical fitness, and academic performance (GARCÍA-HERMOSO et al., 2020). Children were classified according to their performance in the two waves of data collection to analyze changes over time in motor variables: persistently low, decreasing, increasing, or persistently high. The results indicated a positive association between children with higher levels of aerobic fitness and motor skills (persistently high) and academic performance compared to those who maintained lower levels of aerobic fitness and motor skill (persistently low). The changes observed in musculoskeletal fitness, on the other hand, were not associated with academic performance. The studies presented indicate mixed results regarding the association between changes in physical fitness components over time and cognitive performance.

Furthermore, there is a higher prevalence of studies with older children and adolescents. This analysis seeks to fill these gaps by investigating the relationship between changes in non-aerobic physical fitness and cognitive development in preschool-age children. Based on the literature presented, we hypothesize that children with lower levels of non-aerobic physical fitness will, on average, perform poorly in mathematics and language.

6.2.1 Methods

The sample and instruments used in these analyses are the same as in the previous section. However, to analyze changes in non-aerobic physical fitness, we classified children's performance in the Sitting-Rising Test as high or low according to the 25th percentile of the sample distribution in each wave of data collection, similar to the study by García-Hermoso et al. (2020). According to this, see below[11]:

- Wave 1: Low performance = 0 – 7.5 High performance = 8 – 10.
- Wave 2: Low performance = 0 – 8 High performance = 8,5 – 10.
- Wave 3: Low performance = 0 – 8,5 High performance = 9 – 10.

Thus, for each child, the change in non-aerobic physical fitness was calculated as follows, creating four categories of analysis: a) *persistently high*, considering the child who maintained high performance in the 2 Waves of data collection; b) *increasing*, considering the child who had low performance in the 1st wave and high performance in the 2nd wave; c) *decreasing*, considering the child who had high performance in the 1st wave and low performance in the 2nd wave; d) *persistently low*, considering the child who maintained low performance in the 2 Waves of data collection.

In the descriptive analysis of the data, we will present proportions of the number of children classified as having high or low performance in each wave of data collection and, for changes in non-aerobic physical fitness, proportions of the four analysis categories in the first and second year of preschool (Wave 1-Wave 2 and Wave 2-Wave3, respectively). The relationship between changes in non-aerobic physical fitness and

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[11] The categories of Waves 2 and 3 did not exactly correspond to the 25th percentile (1st quartile). Therefore, they were adjusted to the SRT's ordinal scale so that the reference values represented a proportional number of cases. For example, the 1st quartile of the SRT distribution in Wave 2 is the value "8.5", but this corresponds to 31.5% of cases. In Wave 3, the 1st quartile of the SRT distribution is the value "9" and corresponds to 35.1% of cases.

cognitive performance was estimated using hierarchical linear regressions, with the reference category being the child with *persistently high* performance.

For the first year of preschool, four models were estimated using the cognitive measures in Wave 2 as the dependent variable. Model 1 adjusted the analysis by sex, age, diagnosis for special educational needs, and socioeconomic level. Model 2 included the cognitive measure of the beginning of the year. Model 3 included the measure of socioeconomic status at level 2 (school). Finally, Model 4 included the measurement of the children's body composition. For the second year of preschool, cognitive measures in Wave 3 were used as the dependent variable, and those collected in Wave 2 were used as baseline measures. The same models were estimated, except for Model 4, given the impossibility of collecting body composition measurements in Waves 2 and 3.

The Appendix section presents supplementary models estimated using different modeling strategies of the Sitting-Rising Test. The main idea is to verify the robustness of the results considering that: i) the SRT has a ceiling effect in children in this age group; ii) the choice of the cutoff point for the categories was arbitrary, despite being widely used in other similar studies. The first strategy uses the merger of the SRT's underperforming categories in the second wave of the year analyzed (*decreasing* + *persistently low*). The second combines the categories representing an inconsistent trajectory throughout the analyzed year (*increasing* + *decreasing*).

6.2.2 Results

Table 6.8 presents descriptive information of children according to their performance on the SRT in each wave of data collection. As demonstrated in the previous section, SRT mean scores tend to increase over time (see table 6.2). The values for the high and low performance categories also change according to the wave of data collection.

Table 6.8: Classification of SRT's Performance in each wave of data collection

	N	%
Wave 1		
SRT High (8-10)	1984	74,6
SRT Low (≤ 7.5)	677	25,4
Total	2661	100
Wave 2		
SRT High (8.5-10)	2139	76,0
SRT Low (≤ 8)	674	24
Total	2813	100
Wave 3		
SRT High (9-10)	2718	76,5
SRT Low (≤ 8.5)	834	23,5
Total	3552	100

Note: SRT High = Sitting-Rising Test performance above the 25th percentile of the distribution. SRT Low = Sitting-Rising Test performance below the 25th percentile of the distribution.

Table 6.9 presents the descriptive statistics of children regarding changes in non-aerobic physical fitness in the 1st and 2nd year of preschool. As previously presented, the SRT measure has a ceiling effect for this age group. In the first year of preschool, most children maintain high scores in both waves of data collection (61.2% - *Persistently high*), and a smaller portion improves their performance (15.8% - *Increasing*). After that, a small part decreases the performance (13.9% - *Decreasing*), and finally, a small group of children remains with low scores (9.1% - *Persistently low*).

In the second year of preschool, changes in non-aerobic fitness are similar to changes in the first year in all categories of analysis. Children with *persistently high* performance account for most cases (64.6%), and those who have improved their performance represent 14% of cases. In addition, children who have decreased performance account for 12%, and those classified as *persistently low* performers represent 9.4% of cases.

Table 6.9: Descriptive statistics of children regarding the SRT's categories in the 1st and 2nd year of preschool

	N	%	Age*	Boy †	Ponderal Index	SEN †	Language*	Mathematics*
First year of preschool								
Persistently high (SRT High W1 – SRT High W2)	1337	61.2	4.47 (.34)	48.2%	41.07 (1.38)	01%	.39 (.80)	-1.68 (1.34)
Increasing (SRT Low W1 – SRT High W2)	346	15.8	4.36 (.31)	58.6%	40.59 (1.48)	02%	.12 (.74)	-2.08 (1.25)
Decreasing (SRT High W1 – SRT Low W2)	304	13.9	4.42 (.30)	57.2%	40.20 (1.78)	04%	.19 (.90)	-1.93 (1.38)
Persistently low (SRT Low W1 – SRT Low W2)	199	9.1	4.34 (.31)	68.3%	39.91 (2.09)	10%	-.12 (.90)	-2.39 (1.37)
Total	2186	100						
Second year of preschool								
Persistently high (SRT High W2 – SRT High W3)	1496	64.6	5.11 (.33)	48.4%	-	01%	1.01 (.93)	-.40 (1.44)
Increasing (SRT Low W2 – SRT High W3)	324	14	5.06 (.32)	62.9%	-	03%	.80 (.84)	-.78 (1.55)
Decreasing (SRT High W2 – SRT Low W3)	277	12	5.08 (.35)	57.7%	-	02%	.90 (.99)	-.53 (1.50)
Persistently low (SRT Low W2 – SRT Low W3)	218	9.4	5.05 (.30)	63.3%	-	13%	.63 (1.08)	-.93 (1.70)
Total	2315	100						

Note: Age refers to Wave 1 in the first year, and Wave 2 in the second year. W1= Wave 1. W2= Wave 2. SRT High = Sitting-Rising Test performance above the 25th percentile of the distribution. SRT Low = Sitting-Rising Test performance below the 25th percentile of the distribution. In the first year of preschool, the cognitive measures (Language and Mathematics) refer to Wave 2, while in the second year, the same measures refer to Wave 3. *mean (SD) †proportions.

The boxplots in Figures 6.3 and 6.4 present visual information regarding the relationship between the SRT change scores categories in the first year of preschool and cognitive measures at Wave 2. Further details regarding SRT change scores categories in the second year of preschool and Waves 3 cognitive measures are available in the appendix (Figures 10.5 and 10.6).

Figures 6.3 and 6.4 illustrate that a persistently high trajectory of SRT's scores through the first year of preschool had a slightly higher median score in cognitive measures than the other categories. Nevertheless, there is substantial variation in each SRT change score category which does not indicate a strong association. For example, some children with persistently low performance in the SRT presented high mathematics and language scores at Wave 2. The same trends could be observed in Figures 10.5 and 10.6 (appendix).

Figure 6.3: Boxplot with SRT change scores (first year of preschool) and Mathematic performance - Wave 2

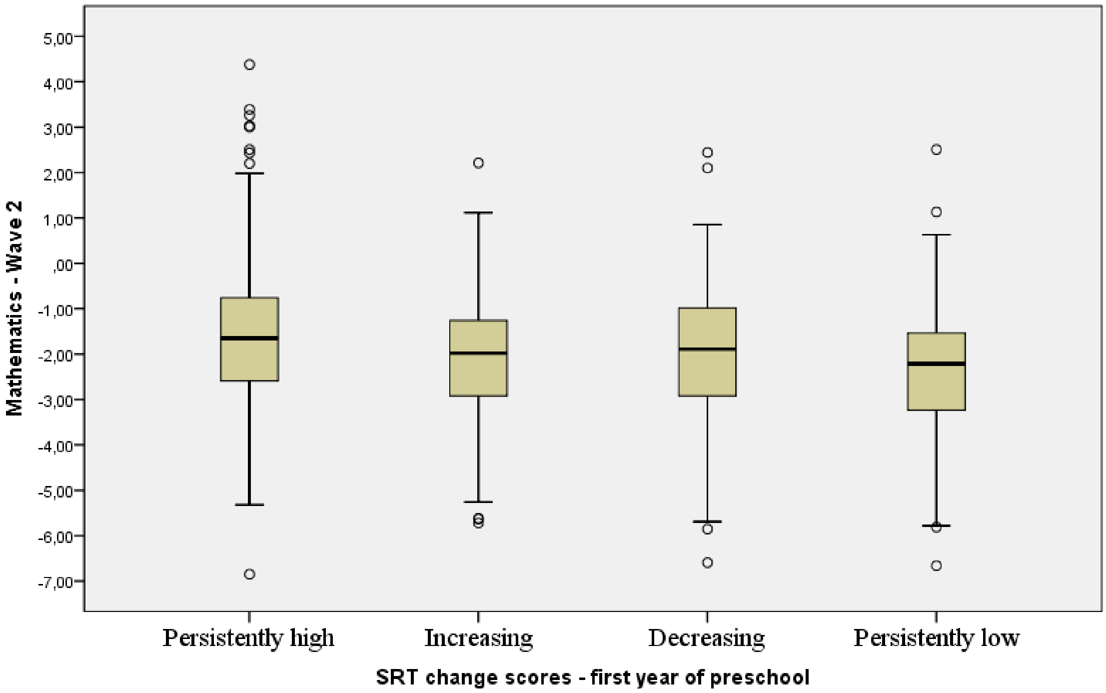
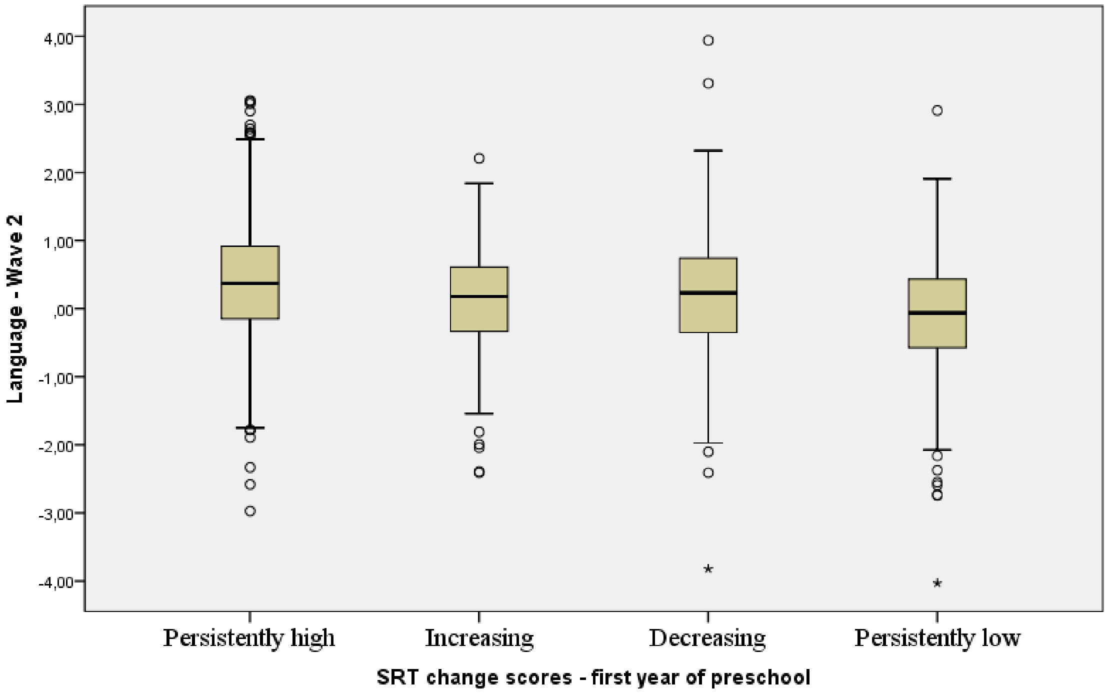


Figure 6.4: Boxplot with SRT change scores (first year of preschool) and Language performance - Wave 2



Tables 6.10 and 6.11 (Mathematics and Language, respectively) present the results of the four hierarchical linear regression models estimated to analyze the relationship between changes in non-aerobic physical fitness in the first year of preschool and cognitive performance in Wave 2. In addition, the calculation of effect sizes for the coefficients related to changes in non-aerobic physical fitness was carried out based on the approach by Tymms (2004). Since the SRT change scores were considered a dichotomous variable in the models, the formula for the calculation is:

$$ES = \frac{\beta 1}{\sigma \mathrm{e}}$$

Where:

β_1 is the SRT change score coefficient

σ_e is standard deviation at child level in the null model

Table 6.10: Hierarchical linear regression models estimating 2nd Wave mathematics measurements (first year of preschool) – Changes in non-aerobic physical fitness

	Model 1	Model 2	Model 3	Model 4
Mathematics				
SRT *increasing*	**-0.24** (0.08)	-0.05 (0.06)	-0.06 (0.06)	-0.07 (0.06)
SRT *decreasing*	**-0.20** (0.08)	-0.09 (0.06)	-0.09 (0.06)	-0.10 (0.07)
SRT *Persistently low*	**-0.51** (0.10)	**-0.25** (0.07)	**-0.25** (0.07)	**-0.20** (0.08)
SEX	0.03 (0.06)	0.05 (0.04)	0.05 (0.04)	0.05 (0.04)
AGE	**0.43** (0.03)	**0.12** (0.02)	**0.12** (0.02)	**0.13** (0.03)
SES	**0.34** (0.03)	**0.12** (0.02)	**0.12** (0.02)	**0.12** (0.02)
SEN	**-0.87** (0.18)	**-0.73** (0.13)	**-0.73** (0.13)	**-0.45** (0.15)
Mathematics (baseline)		**0.95** (0.02)	**0.94** (0.02)	**0.95** (0.02)
Ponderal Index				0.01 (0.03)
SES (school)			0.04 (0.03)	0.03 (0.02)
Explained variance				
school	37%	71%	71%	86%
child	18%	57%	57%	57%
ICC	0.04	0.03	0.03	0.02
Null model				
Var (school)	0.09			
Var (child)	1.77			
ICC	0.05			
N	1956	1956	1956	1606

Note: SRT = Sitting-Rising Test; SEN special educational needs; SES = socioeconomic status; ICC = intraclass correlation coefficient. Significant correlation coefficients in bold ($p < 0.05$).

In Model 1, compared with children who maintained their *persistently high* performance (reference) on the Sitting-Rising Test, all other categories showed lower cognitive performance (*increasing*, ES= -0.17; *decreasing*, ES= -0.14; *persistently low*, ES= -0.35). By including the baseline measure of mathematics performance, Model 2 increased its explained variance from the null model (71% at the school level; 57% at the child level), and only the category of those with *persistently low* SRT performance became remained significant, with an effect size of -0.33. Additionally, Model 3 did not show considerable differences, and, in Model 4, the explained variance concerning the null model was 86% at the school level and 57% at the child level. The results indicated that having a *persistently low* performance on the SRT throughout the first year of preschool represents an effect size of -0.26 on mathematics performance, controlling for all variables in the model.

The replications using the combined categories of *decreasing* and *persistently low* (Table 10.1, appendix) indicated similar results, with a negative association of SRT with performance in Mathematics and significant coefficients, but slightly lower in magnitude. In addition, in Model 4, those children who, regardless of SRT performance in Wave 1, performed poorly in Wave 2, showed lower mathematics scores compared to children who maintained their performance *persistently high* (ES= -0.18), controlling for all model variables. The other replication strategy, which joined the *increasing* and *decreasing* categories (Table 10.5, appendix), also indicated results in the same direction. The categories that represented an inconsistent SRT trajectory throughout the year showed a negative association with performance in Mathematics in Wave 2, but only significant in Model 1.

Table 6.11: Hierarchical linear regression models estimating 2nd Wave language measurements (first year of preschool) – Changes in non-aerobic physical fitness

	Model 1	Model 2	Model 3	Model 4
Language				
SRT *increasing*	**-0.18** (0.05)	-0.02 (0.04)	-0.02 (0.04)	-0.01 (0.04)
SRT *decreasing*	**-0.17** (0.05)	**-0.10** (0.04)	**-0.11** (0.04)	**-0.15** (0.04)
SRT *Persistently low*	**-0.34** (0.06)	-0.03 (0.05)	-0.03 (0.05)	-0.01 (0.05)
SEX	**-0.09** (0.03)	-0.01 (0.03)	-0.01 (0.03)	-0.01 (0.03)
AGE	**0.26** (0.02)	**0.09** (0.02)	**0.09** (0.02)	**0.10** (0.02)
SES	**0.19** (0.02)	**0.06** (0.01)	**0.06** (0.01)	**0.05** (0.01)
SEN	**-0.82** (0.11)	**-0.39** (0.08)	**-0.40** (0.08)	**-0.30** (0.10)
Language (baseline)		**0.54** (0.02)	**0.54** (0.02)	**0.55** (0.02)
Ponderal Index				-0.02 (0.02)
SES (school)			**0.04** (0.02)	0.03 (0.02)
Explained variance				
school	25%	52%	59%	67%
child	22%	53%	53%	54%
ICC	0.05	0.05	0.05	0.04
Null model				
Var (school)	0.04			
Var (child)	0.69			
ICC	0.05			
N	1956	1956	1956	1606

Note: SRT = Sitting-Rising Test; SEN special educational needs; SES = socioeconomic status; ICC = intraclass correlation coefficient. Significant correlation coefficients in bold ($p < 0.05$).

The changes in non-aerobic physical fitness and cognitive performance in language (Wave 2) presented a negative association. In Model 1, compared to the reference category, all other categories showed lower cognitive performance (*increasing*, ES= -0.33; *decreasing*, ES= -0.32; *persistently low*, ES= -0.64). When including the baseline cognitive measure of language, Model 2 presented greater explained variance concerning the null model, with 52% at level 2 (school) and 53% at level 1 (child), and *decreasing* was the only statistically significant category with effect size -0.32. Model 3 did not show consistent changes in the coefficients. In Model 4, an explained variance of 67% at level 2 and 54% at level 1 compared with the null model. After controlling for all the variables in the model, the results suggest that decreasing SRT's performance during the first year of preschool negatively associates with the performance in language (ES= -0.33).

The complementary analyses presented in Table 10.2 (appendix) indicate the same direction. In the final model, when comparing with the reference category, children who had low performance in the SRT in Wave 2 (*decreasing and persistently low*) presented, on average, a lower performance in language (ES= -0.29). Furthermore, the models that used the combined categories of *increasing* and *decreasing* (Table 10.6, appendix), indicated that this category showed a negative association with the performance in Language in Wave 2, but with a lower magnitude than that presented by the *decreasing* category in Table 6.11.

The three models used to analyze the relationship between changes in non-aerobic physical fitness in the second year of preschool and cognitive performance in mathematics and language in Wave 3 are presented in Tables 6.12 and 6.13, respectively.

Table 6.12: Hierarchical linear regression models estimating 3rd Wave mathematics measurements (second year of preschool) – Changes in non-aerobic physical fitness

	Model 1	Model 2	Model 3
Mathematics			
SRT *increasing*	**-0.31** (0.09)	-0.08 (0.06)	-0.08 (0.06)
SRT *decreasing*	-0.12 (0.10)	0.01 (0.07)	0.02 (0.07)
SRT *Persistently low*	**-0.41** (0.11)	-0.13 (0.07)	-0.13 (0.07)
SEX	**0.15** (0.06)	**0.18** (0.04)	**0.18** (0.04)
AGE	**0.47** (0.03)	**0.13** (0.02)	**0.13** (0.02)
SES	**0.31** (0.03)	**0.05** (0.02)	**0.05** (0.02)
SEN	**-1.51** (0.19)	**-0.85** (0.13)	**-0.85** (0.13)
Mathematics (Wave 2)		**1.13** (0.02)	**1.12** (0.02)
SES (school)			**0.05** (0.02)
Explained variance			
school	25%	76%	77%
child	21%	64%	64%
ICC	0.05	0.03	0.03
Null model			
Var (school)	0.12		
Var (child)	2.32		
ICC	0.05		
N	2082	2082	2082

Note: SRT = Sitting-Rising Test; SEN special educational needs; SES = socioeconomic status; ICC = intraclass correlation coefficient. Significant correlation coefficients in bold (p <0.05).

For mathematics in Model 1, compared to children who maintained a persistently high performance on the SRT through the second year of preschool, children classified as *increasing* their performance on the SRT had lower cognitive performance (ES= -0.17). Children classified as having a persistently low non-aerobic physical fitness performance showed even lower cognitive performance (ES= -0.22). With Model 2, there was an increase in explained variance compared to the null model (76% school level and

64% child level). However, none of the categories related to changes in non-aerobic physical fitness was associated with cognitive performance. Model 3 did not show substantial changes in the coefficients of the variables of interest. In fact, in the final model, we only identified a borderline association (p=0.081) between persistently low SRT performance and Wave 3 mathematics performance (ES= -0.15).

The replications using the combined categories of *decreasing* and *persistently low* (Table 10.3, appendix) only indicated significant associations between the trajectory of non-aerobic physical fitness and mathematics performance in Model 1. Furthermore, when replicating the analyzes using the combined categories of *increasing* and *decreasing* (Table 10.7, appendix), we identified a negative and significant association between the *persistently low* SRT category and the mathematics performance in Wave 3 in Model 1 (ES= -0,23). Additionally, Models 2 and 3 identified a relationship of the same magnitude (ES= -0.16) but with borderline statistical significance (p=0.076 and p=0.08, for Models 2 and 3, respectively).

Table 6.13: Hierarchical linear regression models estimating 3rd Wave language measurements (second year of preschool) – Changes in non-aerobic physical fitness

	Model 1	Model 2	Model 3
Language			
SRT increasing	**-0.15** (0.05)	-0.04 (0.04)	-0.04 (0.04)
SRT decreasing	-0.04 (0.06)	0.03 (0.04)	0.03 (0.04)
SRT *Persistently low*	**-0.27** (0.07)	-0.06 (0.05)	-0.06 (0.05)
SEX	**-0.14** (0.04)	**-0.06** (0.03)	**-0.06** (0.03)
AGE	**0.28** (0.02)	**0.08** (0.02)	**0.08** (0.02)
SES	**0.19** (0.02)	**0.05** (0.01)	**0.05** (0.01)
SEN	**-1.06** (0.12)	**-0.33** (0.08)	**-0.33** (0.08)
Language (baseline)		**0.67** (0.01)	**0.67** (0.01)
SES (school)			0.02 (0.02)
Explained variance			
school	06%	49%	52%
child	18%	60%	60%
ICC	0.09	0.10	0.10
Null model			
Var (school)	0.07		
Var (child)	0.83		
ICC	0.08		
N	2082	2082	2082

Note: SRT = Sitting-Rising Test; SEN special educational needs; SES = socioeconomic status; ICC = intraclass correlation coefficient. Significant correlation coefficients in bold ($p < 0.05$).

The results for language in the second year of preschool are similar to those found for mathematics. In Model 1, children who increased their SRT performance had, on average, lower cognitive performance (increasing, ES= -0.22), and those with *persistently low* SRT performance showed a negative association with cognitive performance (ES= -0.40). In Models 2 and 3, no association was identified between changes in non-aerobic physical fitness and cognitive performance in language at Wave 3.

The complementary models in Table 10.4 (appendix) did not indicate substantial differences in the analyses. The combined variable with the categories decreasing and persistently low showed significant results only in Model 1, with effect size -0.21. Likewise, the results presented in Table 10.8 (appendix) indicate a negative and significant association of the category increasing and decreasing only in Model 1 (ES=-0.15).

6.2.3 Discussion

This section aimed to longitudinally analyze the relationship between changes in non-aerobic physical fitness and cognitive development in preschool children at two different time points (1st and 2nd year of preschool). In the first year of preschool, the results indicated that having a *persistently low* performance in the SRT, compared with a *persistently high* performance, is related to lower performance in mathematics, controlling for all the variables in the models. On the other hand, having a high performance in the SRT at the beginning of the year and a low performance at the end of the 1st year of preschool ("*decreasing*"), compared with a performance *persistently high*, is related to lower scores in language. These results contrast with those of the previous section, where no association was found between baseline SRT measures (Wave 1) and prospective language performance (Wave 2 and 3). These contrasting results reinforce the importance of longitudinal data to observe the phenomena related to the association between physical fitness and cognition in children.

The results for the second year of preschool, in mathematics, showed similar results to those found for the first year. The association between *persistently low* performance in the SRT and cognitive performance in mathematics at Wave 3 was only borderline. However, it is noteworthy to observe this result more closely. The direction of the association remained constant, and the magnitude found in the final model (Model 3), despite being small (ES= -0.15) and smaller than that found in the analyzes of the 1st year of preschool, is not negligible. Similarly, considering the results of the previous section (6.1), the effect sizes of the relationship between SRT and mathematics performance also decreased from one year to another (ES= 0.16; 0.11 at the end of the year first and second year of preschool, respectively). Here, it is not a matter of abandoning the use of appropriate limits of statistical significance, but of not using it in a dichotomous and exclusive way for the interpretation of a scientific phenomenon (AMRHEIN; GREENLAND; MCSHANE, 2019).

Moreover, in the second year of preschool, the association between changes in non-aerobic physical fitness and cognitive performance in language did not show statistical significance. Besides that, the confidence intervals for the estimates do not indicate a clear trend in the results. Additionally, the check for robustness with the replications models at both first and second preschool years showed results in the same direction and similar magnitude.

Previous longitudinal studies that analyzed the relationship between changes in the non-aerobic physical fitness components and cognition in children and adolescents showed contrasting results with those presented in this section. For example, a study with 669 adolescents (CHEN et al., 2013) showed that changes in non-aerobic components of physical fitness (muscular strength and flexibility) were not associated with their academic performance. However, there was a trend similar to this section's results. Students with persistently high performance in muscular strength and flexibility exhibited higher academic scores compared to the persistently low performance group. Although not using an academic performance measure, another study of 371 children aged 6-9 years (HAAPALA et al., 2019) found no significant associations between changes in agility and balance and the performance on the Raven Colored Progressive Matrices, which assesses the main components of executive functions. Unfortunately, the authors did not report these results' figures for further comparison. However, modeling the dependent variable as change scores might be problematic (CRONBACH; FURBY, 1970) and may not allow for associations to be observed.

The results presented in this section, on the other hand, are in line with the study by Syväoja et al. (2019), which indicated that changes in musculoskeletal fitness (abdominal and upper limb strength) were positively related to the academic performance of 954 children and adolescents aged 9-15 years. However, some differences between these previous studies and the presented analyses are worth considering. For example, they did not analyze preschool children, used different instruments to measure physical fitness components and academic/cognitive performance, and used other analytical approaches, contributing to the different results.

As already mentioned, the SRT is a screening tool assessing the individual's non-aerobic physical fitness components (muscular strength/power, flexibility, balance, and body composition). From the motor development's point of view, an infant can sit with support in the lumbar region for around five months of age. After gradually developing, between 12 to 15 months, the infant has gained considerable control over the musculature and can maintain an upright posture and walk alone (GALLAHUE; OZMUN; GOODWAY, 2019; SHIRLEY, 1931). Thus, when evaluating rudimentary motor skills learned very early and practically culturally independent, the SRT theoretically excludes the possibility of benefiting skilled individuals (e.g., stability and locomotor skills). Hence, it is likely that the SRT may be measuring or capturing other aspects of the child's development beyond the non-aerobic physical fitness components. Consider the example of a 4-year-old child scoring 7.5 on the SRT. Why did the child get that score? Objectively, it was identified that the child used two supports to perform the test, and the evaluator noticed an unsteady execution during the actions. In some way, the SRT may capture a proxy of the level of physical activity, motor experiences lived so far, and some adverse changes in non-aerobic physical fitness components (factors related to motor development).

In addition to the limitations presented in the previous section, we included the choice of categorizing children into high or low performance in the SRT (cut-off point = 25th percentile). This cut-off is arbitrary and may not have allowed us to observe the changes that occurred longitudinally in a precise way. For example, children who achieved an SRT score of 4.0 in Wave 1 and 8.0 in Wave 2 (4-point increment) were classified as persistently low performers in the first year of preschool. On the other hand, children with an SRT score of 8.0 in Wave 1 and 8.5 in Wave 2 were classified as having a persistently high performance despite the low increment in the final score. Furthermore, we obtained very heterogeneous group sizes with this categorization (*persistently high*; *increasing*; *decreasing*; *persistently low*), most classified as *persistently high*. Nevertheless, this approach (high or low performance in physical fitness components, using the first quartile as a cut-off point) has been widely used in the literature that analyzes the relationship between physical fitness and cognition (CHEN et al., 2013; GARCÍA-HERMOSO et al., 2020; SARDINHA et al., 2016; SOLIS-URRA et al., 2021).

6.2.4 Conclusion

The results presented here reinforce those reported in the previous section, especially for the relationship between non-aerobic physical fitness and mathematics performance, considering the two years of preschool. Regarding the results of language performance, in the analysis of this section, it was found that, in the 1st year of preschool, compared to the group that had a persistently high performance in the SRT, the group classified as "*decreasing*" presented a lower performance in language. However, the same did not happen in the group with *persistently low* performance on the SRT. These different results suggest that the relationship between non-aerobic physical fitness and language is more uncertain than that found for mathematics, which is in line with the results of other systematic reviews (ÁLVAREZ-BUENO et al., 2017; FEDEWA; AHN, 2011; SINGH et al., 2018).

7 THE IMPACT OF PRESCHOOL ATTENDANCE ON NON-AEROBIC PHYSICAL FITNESS

7.1 Introduction

This chapter aims to analyze the effect of preschool attendance on non-aerobic physical fitness, an element of motor development. In Brazil's educational system, one of the main goals of Early Childhood Education (ECE) is to enhance children's development considering the cognitive, socio-emotional, and motor dimensions (BRASIL, 2017). In the early stages of development, the effect of experiences on the children's brain and body is particularly strong, making it possible to observe that skills and learning occur in an accelerated way. These periods are referred to as sensitive or critical periods (KNUDSEN, 2004; LENT; OLIVEIRA, 2018). Furthermore, the development of motor dimensions is influenced not only by maturation but also by environmental factors such as environmental conditions, opportunities for practice, encouragement, and instruction (GALLAHUE; OZMUN; GOODWAY, 2019; HAYWOOD; GETCHELL, 2014).

In line with the national curriculum (*Base Nacional Curricular Comum* - BNCC) and with guidelines for pedagogical practices for ECE, the school environment represents a crucial factor in children's development. For example, the city of Rio de Janeiro provides a comprehensive Curriculum Guidelines for Early Childhood Education (*Orientações Curriculares para a Educação Infantil*) (RIO DE JANEIRO, 2010, 2020), which highlights the need to provide opportunities for children's learning and development intentionally. These development opportunities must be centered on routines with social interactions and play. In this regard, physical education (PE) classes represent an encouraging moment to know and experience the plurality of human movement, favoring an active and healthy life (BRASIL, 2021).

Additionally, the Curriculum Guidelines suggest carefully organizing time and space, seeking to provide practices and experiences as self-care; taking care of other children and the environment; material and environment exploration; movement, and body expression. Moreover, the Curriculum Guidelines indicate that ECE practices must produce an integrated concept of development considering and respecting the children's needs and demands (RIO DE JANEIRO, 2010, 2020). Finally, beyond the Curriculum Guidelines, the beginning of compulsory education may provide a more structured and physically active routine for the children, including active commuting to school (i. e., on foot or by bicycle) (BRASIL, 2021).

The impact of ECE on children's development represents a potentially effective strategy for reducing educational inequalities. Indeed, studies investigating the effects of attending preschool and ECE centers indicate positive cognitive and socioemotional effects, especially for children from low socioeconomic status (PEISNER-FEINBERG et al., 1999; SYLVA et al., 2010). Furthermore, considering that SES is a crucial determinant of health outcomes (CSDH, 2008) and low SES families are less likely to engage in sufficient physical activity (WILSON et al., 2004), low SES children could benefit from opportunities and practices delivered in ECE centers. Therefore, the hypothesis indicate that children who attended preschool will show higher non-aerobic physical fitness levels, compared to other children of similar age that have not experienced preschool. In addition, the effect of preschool attendance on non-aerobic physical fitness will be higher for children from low SES families.

7.2 Methods

7.2.1 Participants and study design

This chapter uses data from the longitudinal study described on Chapter 4. Children unable to participate in physical assessments were excluded from the analysis. However, those diagnosed with special educational needs (SEN), such as ADHD, Down syndrome, autism spectrum disorder, participated in the study and were included in the analysis. The analyses considered children assessed in the first year of preschool (Wave 1 and 2).

The age cut-off established to enrollment in the first year of preschool implies a wide age range within the same school year. Therefore, in the first year of preschool a group of children within the same age group (4.5 to 5 years old, N=2229) was distributed in the two waves of data collection – start and end of the first year at school. This age range allowed analysis with two groups that differed in the opportunity to attend preschool. Children identified as "Wave 1" are from the group that was assessed at the beginning of the school year (March/April 2017) and had not yet had attended preschool. Those identified as "Wave 2" took the assessments at the end of the school year (November/December 2017). Thus, children from Wave 2 will be coded as "intervention", and those from Wave 1 as "control". The time difference between the end of the Wave 1 and the beginning of the Wave 2 exceeds six months. Therefore, this difference means that the analyses will comprise two independent samples according to the age group analyzed.

Next, we present the experimental design of the analyzes in this chapter with widely used notations (CAMPBELL; STANLEY, 1963; GORARD, 2013). The first line represents the group that did not attend preschool, and the second line the group that did. The notation "X" represents the intervention (preschool attendance) while "O" represents the observation (data collection). The allocation into groups was not random, and the temporal sequence goes from left to right.

O X
X O

Although there was no "true" random allocation in the groups, it is possible to consider the treatment assignment plausibly "as if" random (DUNNING, 2008). In this sense, both groups could be seen as equivalent in expectancy. Considering the cut-off date for enrollment in the first year of preschool (four years until March 31 of the current year), what determined the allocation in the groups was the child's date of birth. For example, a child who was born in July of 2012 was "allocated" in the control group (Wave 1, 2017), having approximately 4.75 years (four years and nine months). Conversely, another child born in March 2012 belonged to the intervention group (Wave 2, 2017) with barely the same age. To the best of our knowledge, there is no evidence of an association between birth date and contextual factors that could benefit non-aerobic physical fitness performance (e.g., more physically active families or more engaged in promoting motor development opportunities for their children). Conversely, a systematic review (HEMATI et al., 2021) investigating factors related to future anthropometric measures in children suggests that individuals born in the cold season (winter month) have higher BMI and weight in childhood. However, most of the studies included in this review were from northern hemisphere countries that face more severe winter seasons.

7.2.2 Data analyses

Data are presented as mean and standard deviation, median and interquartile range, or proportions. The Mann-Whitney test was utilized to examine the effect of preschool attendance on non-aerobic physical fitness, using the Sitting-Rising Test (SRT) as the outcome variable. Table 7.1 presents the three analysis models to investigate the effect of preschool attendance on non-aerobic physical fitness. Each model investigated the differences in non-aerobic fitness levels between the intervention and control groups. Additionally, complementary analyses controlling sex and socioeconomic status (SES) were estimated. The first quartile of SES distribution represented the low SES group, while the upper quartile represented the high SES group.

Table 7.1: Analysis models to examine the effect of preschool attendance on non-aerobic physical fitness

	Model 1		Model 2		Model 3	
Age group (years)	i)	4.5 – 5	i)	4.5 – 4.75	i)	4.5 – 4.66
			ii)	4.75 – 5	ii)	4.66 – 4.83
					iii)	4.83 – 5

Model 1 presents a single age group with an age range of 6 months (4 years and six months to 5 years). In model 2, the age range reduces to 3 months, with two age groups (4 years and six months to 4 years and nine months; 4 years and nine months to 5 years). Finally, in model 3, three age groups differed in 2 months (4 years and six months to 4 years and eight months; 4 years and eight months to 4 years and ten months; 4 years and ten months to 5 years old). Effect sizes for the results of Mann-Whitney test were calculated using η^2 (eta squared), given by the formula: $\eta^2 = Z^2 / N$. After that, these effect sizes were transformed to Cohen's d since it is often more used in educational and social sciences. The formula for converting η^2 into d is given by[12]:

$$d = \frac{2 * \sqrt{\eta 2}}{\sqrt{1} - \eta 2}$$

A three-step hierarchical linear regression model was estimated using a different approach to replicate the analyses further. Again, the dependent variable was the SRT performance. First, preschool attendance (children at Wave 2 – intervention group), sex, and age were the independent variables entered in Model 1. Second, a variable indicating

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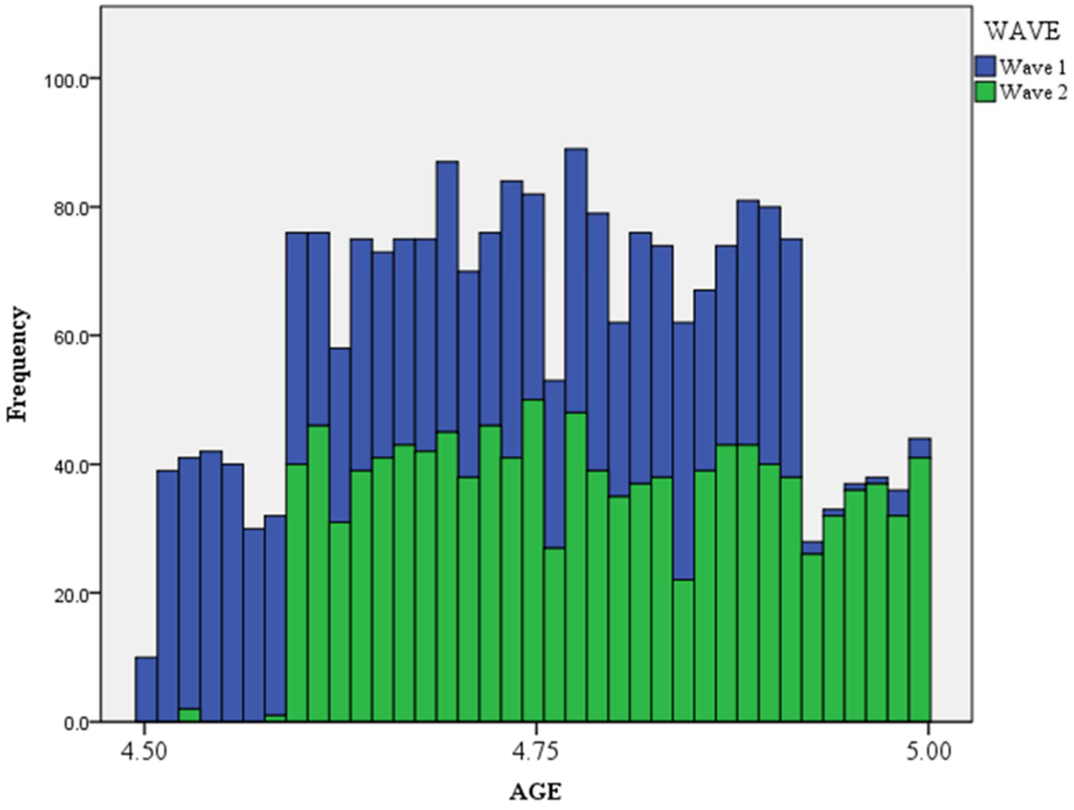
[12] To detailed information on calculation and transformation of effect sizes, see Fritz, Morris, and Richler (2012)

children from low SES families was entered in Model 2 (low SES = first quartile of the SES distribution). Finally, Model 3 included an interaction term (Low SES* Preschool attendance) to analyze if the effect of preschool on the SRT depends on SES. Effect sizes for the results of the hierarchical linear regression model were calculated using the approach suggested by Tymms (2004), described in Chapter 6. The analyses were made using SPSS version 23. All testing was two-tailed and at a significance level of 5% of probability. The effect size for the hierarchical linear regression model was calculated using the approach suggested by Tymms (2004).

7.3 Results

Figure 7.1 presents the histogram of the children's age with the overlap of the two analysis groups (Wave 1 and Wave 2).

Figure 7.1: Children's age in the control and intervention groups (Wave 1 and 2, respectively)



It is possible to notice that the distribution of the groups in the age groups is balanced, except in the edges. For example, the age group that goes from 4.5 years to approximately 4.59 has more children belonging to Wave 1. On the other hand, in the range from 4.92 to 5 years of age, has more cases of Wave 2. Since the SRT performance is positively associated with age, older children tend to have higher scores than younger children, the three models intend to deal with this threat.

Table 7.2 presents descriptive statistics considering data collection waves and models that progressively control the age effect.

Table 7.2: Descriptive statistics of participants in each analysis model

Age group	Wave	N	SRT †	Sex (boy) %	Age (years) *	SES *
Model 1						
4.5 - 5	1	1071	9 (8 - 10)	0.52	4.71 (0.12)	.27 (1.39) [a]
	2	1158	9 (8 - 10)	0.54	4.78 (0.12)	.30 (1.45) [b]
Model 2						
4.5 - 4.75	1	622	9 (8 - 10)	0.54	4.62 (0.07)	.27 (1.39) [c]
	2	485	9.5 (8 - 10)	0.54	4.67 (0.05)	.24 (1.38) [d]
4.75 - 5	1	449	9 (8 - 10)	0.49	4.83 (0.05)	.26 (1.38) [e]
	2	673	9 (8 - 10)	0.53	4.87 (0.07)	.33 (1.49) [f]
Model 3						
4.5 - 4.66	1	413	9 (8 - 10)	0.55	4.58 (0.05)	.28 (1.45) [g]
	2	229	9 (8 - 10)	0.54	4.62 (0.02)	.19 (1.28) [h]
4.66 - 4.83	1	427	9 (8 - 10)	0.50	4.75 (0.05)	.27 (1.33) [i]
	2	497	9.5 (8 - 10)	0.55	4.74 (0.05)	.32 (1.44) [j]
4.83 - 5	1	231	9 (8 - 10)	0.49	4.88 (0.03)	.24 (1.40) [l]
	2	432	9 (8.5 - 10)	0.55	4.91 (0.05)	.32 (1.52) [m]

Note: SRT = Sitting-Rising Test; †median (interquartile range: P25-75); % proportions; *mean (standard deviation); a (n=912); b (n=1031); c (n= 518); d (n= 428); e (n=394), f (n= 603); g (n=349); h (n=209); i (n=365); j (n=438); l (n=198); m (n=384); SES= socioeconomic status.

The SRT scores are high and close to the maximum value in both groups across all models. These high scores suggest a ceiling effect in children, as demonstrated in other sections of this thesis. Although both groups performed similarly (median= 9; P25-75=

8-10), the intervention group performed slightly better in some models. For example, the age groups *4.5 - 4.75* and *4.66 - 4.83 (*Models 2 and 3 respectively) had median= 9.5, and P25-75= 8-10 in Wave 2. Likewise, in Model 3, the age group *4.66 - 4.83* presented median= 9, and P25-75= 8.5-10.

SRT scores correlate with sex (see Tables 5-4 and 6-3). Girls present, on average, better performance than boys. Therefore, it is important to have balanced groups in the analyses. The proportion of boys and girls was fairly distributed in both groups. However, there was a higher proportion of boys in some models in the intervention group. In Model 1 (*4.5 – 5)*, the group that attended preschool (Wave 2) has a slightly higher proportion of boys compared to the group that did not (Wave 1). In Model 2, the age band *4.75 - 5* has a higher proportion of boys in Wave 2. Finally, in Model 3, the age band *4.66 - 4.83* and *4.83 - 5* have a higher proportion of boys in Wave 2 than the Wave 1 group.

Regarding age, the group of children who attended preschool (Wave 2) tends to be, on average, a little older. Here again, we face a possible threat to the results because, as demonstrated in this thesis, older children tend to have superior results on the SRT. Similarly, other studies have also indicated associations between age and physical fitness in preschoolers (CUPEIRO et al., 2020) and, in children aged 6-11 years (BIRCH et al., 2016), in a phenomenon called the "relative age effect". However, the mean age differences between groups are minimal, ranging approximately between 4 and 25 days (0.01 – 0.07 years). Information about families' socioeconomic profile are based on a reduced number of cases. The superscript letters in the Table 7.2 (a – m) indicate the number of participants with SES information for each group. For example, in the Model 1 there are 912 children who did not attend the preschool (wave 1) and 1031 who did.

Table 7.3 presents the results of the Mann-Whitney test for the differences in SRT between children who attended the first year of preschool and those who did not.

Table 7.3: Differences in SRT performance between intervention and control groups

Age group	Wave	Mean Rank	Mann-Whitney U	Z	p-value	Cohen's *d*
Model 1						
4.5 - 5	1	1072.67	574768.5	-3.063	0.002	0.13
	2	1154.15				
Model 2						
4.5 - 4.75	1	525.55	133137	-3.431	0.001	0.20
	2	590.49				
4.75 - 5	1	555.78	148519	-0.497	0.619	0.03
	2	565.32				
Model 3						
4.5 - 4.66	1	311.19	43032.5	-1.933	0.053	0.15
	2	340.09				
4.66 - 4.83	1	443.58	98030	-2.047	0.041	0.13
	2	478.76				
4.83 - 5	1	326.50	48625	-0.558	0.577	0.04
	2	334.94				

Across all six age groups distributed in the three models, children who attended preschool had higher SRT scores (see Mean Rank column). In Model 1, we observed a statistically significant difference for the age group of *4.5-5* years (ES= 0.13). In Model 2, only the age group between *4.5-4.75* years showed a significant difference, with ES= 0.20. Finally, in Model 3, the age group between *4.5-4.66* years showed a borderline significant difference (p=0.053), with ES= 0.15. In the age group 4.66-4.83, there was a significant difference and ES=0.13, and in the age group 4.83 - 5, there was no difference between the groups.

Next, we will replicate the models previously presented by analyzing them separately by sex. Tables 7.4 and 7.5 present the results for boys and girls, respectively.

Table 7.4: Differences in SRT performance between intervention and control groups - boys

Age group	Wave	N	Mean Rank	Mann-Whitney U	Z	p-value	Cohen's *d*
Model 1							
4.5 - 5	1	554	563.88	158654	-2.292	0.022	0.13
	2	620	608.61				
Model 2							
4.5 - 4.75	1	333	283.37	38752	-2.224	0.026	0.18
	2	260	314.45				
4.75 - 5	1	221	284.27	38293	-0.770	0.442	0.06
	2	360	295.13				
Model 3							
4.5 - 4.66	1	228	170.33	12728.5	-1.446	0.148	0.15
	2	123	186.52				
4.66 - 4.83	1	213	230.27	26255.5	-1.735	0.083	0.16
	2	271	252.12				
4.83 - 5	1	113	167.34	12468	-0.360	0.719	0.04
	2	226	171.33				

The results for preschool attendance on non-aerobic physical fitness of boys indicate very similar results to those presented in Table 7.3. The performance of the preschool group (Mean Rank) is superior to the control group in all models. We observed significant results in the age ranges *4.5 - 5* (Model 1) and *4.5 - 4.75* (Model 2) and effect sizes similar to those presented previously. In model 3, the result for the age range *4.5 - 4.66* did not show statistical significance, but the effect size (0.15) was previously maintained. The age group between *4.66-4.83* years showed only a borderline significant difference (p=0.083), with ES= 0.16. For the age group *4.83–5*, no significant difference was observed for the difference between groups.

Table 7.5: Differences in SRT performance between intervention and control groups - girls

Age group	Wave	N	Mean Rank	Mann-Whitney U	Z	p-value	Cohen's *d*
Model 1							
4.5 - 5	1	517	505.68	127607	-2.421	0.015	0.14
	2	538	549.31				
Model 2							
4.5 - 4.75	1	289	242.48	28172	-2.699	0.007	0.23
	2	225	276.79				
4.75 - 5	1	228	267.41	34863	-0.479	0.632	0.04
	2	313	273.62				
Model 3							
4.5 - 4.66	1	185	141.42	8958	-1.276	0.202	0.14
	2	106	153.99				
4.66 - 4.83	1	214	211.35	22223.5	-1.524	0.128	0.14
	2	226	229.17				
4.83 - 5	1	118	157.42	11554.5	-0.785	0.432	0.08
	2	206	165.41				

The girls' group's analyses indicated results in the same direction as those for boys in models 1 and 2. In model 3, no statistically significant difference was found in the three age groups. However, both age groups, *4.5 - 4.66* and *4.66 - 4.83* had an ES=0.14, similar to those shown in Tables 7.3 and 7.4. The replications of the models with analyzes considering the socioeconomic status are shown in Tables 7.6 and 7.7 (Low SES and High SES, respectively).

Table 7.6: Differences in SRT performance between intervention and control groups - Low SES

Age group	Wave	N	Mean Rank	Mann-Whitney U	Z	p-value	Cohen's *d*
Model 1							
4.5 - 5	1	312	305.52	46495.5	-2.736	0.006	0.21
	2	339	344.85				
Model 2							
4.5 - 4.75	1	178	149.51	10682	-2.630	0.009	0.29
	2	144	176.32				
4.75 - 5	1	134	159.25	12294.5	-0.936	0.349	0.10
	2	195	168.95				
Model 3							
4.5 - 4.66	1	118	87.65	3321.5	-1.688	0.091	0.24
	2	66	101.17				
4.66 - 4.83	1	125	122.40	7425.5	-2.717	0.007	0.32
	2	146	147.64				
4.83 - 5	1	69	101.88	4148	-0.634	0.526	0.09
	2	127	96.66				

The results of the effect of preschool on SRT among low SES children also indicate that those who attended preschool show superior results, except in the age group *4.83 – 5* (Model 3). In model 1, we observed a statistically significant difference for the age group *4.5-5* (ES= 0.21). In model 2, the age group between *4.5-4.75* years showed a significant difference, with ES= 0.29, but this was not observed in the age group 4.75-5. In model 3, the age range *4.5-4.66* showed a borderline significant difference (p=0.091), with ES= 0.24. In the age group *4.66-4.83*, a significant difference and ES=0.32. In the same way as previous analyses, the older age range (*4,83 - 5*) showed no significant difference between the groups.

Table 7.7: Differences in SRT performance between intervention and control groups - High SES

Age group	Wave	N	Mean Rank	Mann-Whitney U	Z	p-value	Cohen's *d*
Model 1							
4.5 - 5	1	321	331.65	54779	-0.047	0.963	0.004
	2	342	332.33				
Model 2							
4.5 - 4.75	1	180	152.05	11079	-0.821	0.411	0.09
	2	130	160.28				
4.75 - 5	1	141	180.75	14417.5	-0.578	0.563	0.06
	2	212	174.51				
Model 3							
4.5 - 4.66	1	121	90.65	3587.5	-1.175	0.240	0.17
	2	66	100.14				
4.66 - 4.83	1	129	141.86	8403	-1.214	0.225	0.14
	2	142	130.68				
4.83 - 5	1	71	99.47	4506.5	-0.636	0.525	0.09
	2	134	104.87				

The analyzes considering children in the upper quartile of the distribution of socioeconomic status (High SES) did not show the same trend as the analyzes presented earlier. The performance of the preschool group on the SRT (see Mean Ranks) was not superior to the control group (Wave 1) in the age groups *4.75 - 5* (Model 2) and *4.66 - 4.83* (Model 3). Moreover, no statistically significant differences were found in any of the proposed models, and all effect sizes were smaller when comparing the models with Low SES children.

Table 7.8 presents the hierarchical linear models estimating the SRT performance to examine the impact of the preschool controlling for sex, age, and SES.

Table 7.8: Hierarchical linear model estimating the SRT - first year of preschool

	Model 1	Model 2	Model 3
Sitting-Rising Test			
Preschool attendance	**0.14** (0.06)	**0.13** (0.06)	0.09 (0.08)
AGE	0.34 (0.23)	0.25 (0.25)	0.25 (0.25)
SEX (boy)	**-0.35** (0.06)	**-0.35** (0.06)	**-0.35** (0.06)
Low SES		-0.06 (0.06)	-0.12 (0.09)
Low SES* **Preschool attendance**			0.11 (0.13)
Explained Variance			
school	4 %	48 %	49 %
child	2 %	3%	3 %
ICC	0.01	0.01	0.01
Null Model			
Var (school)	0.01		
Var (child)	1.81		
ICC	0.01		
N	2229	1943	1943

Note: SEX= boy; SES= socioeconomic status. B= unstandardized coefficients; SE= standard error.

The results corroborate the results presented in previous analyses. In Model 1, preschool attendance showed a positive effect on SRT (ES=0.10), controlling for age and sex. In this multivariate model, the variable "age" did not show statistical significance, which suggests that in the previous models (Tables 7.3, 7.4, 7.5, 7.6, and 7.7), we could control the impact of the relative age effect. The additional adjustment for low SES in Model 2 explained additional variance concerning the null model (48% at school level; 3% at child level). The effect size for preschool attendance did not change (ES=0.10).

To analyze if the effect of preschool attendance depends on the SES, Model 3 included an interaction term (Low SES* Preschool attendance). Although the interaction term suggested that the effect of preschool attendance on the SRT is higher for children from Low SES, the coefficient was not statistically significant.

7.4 Discussion

The results presented in this chapter are intrinsically connected with the extensive field of research on school's effect, adding insights of a dimension of child development little explored in this area, especially in Early Childhood Education. The main objective was to identify the impact of attending the first year of preschool on the non-aerobic physical fitness of children between 4.5 and 5 years of age. The results suggest that attending preschool has a small but positive effect on SRT measures. On the other hand, analyzes using narrow age ranges in our sample (Models 2 and 3) suggest that this effect is significant only for younger children (age range 4.5-4.75 in Model 2; age ranges 4.5-4.66 and 4.66-4.83 in Model 3).

Complementary analyses for boys and girls separately showed the same direction and similar effect sizes as the main analyses that considered all children. This result suggests that attending preschool has the same effect on the motor dimension analyzed in this thesis. On the other hand, the SES analyses indicated that children from families with a lower socioeconomic status benefit more from attending preschool (regarding non-aerobic physical fitness levels) than children from families with a higher socioeconomic status. The SES index uses household information on possession of durable goods and access to services, parents' education level, housing density (number of people per room), and participation in cash transfer programs, a proxy for poverty. Thus, a plausible hypothesis is that children with low SES, on average, have less access to opportunities and factors related to healthy motor development and, therefore, are the most benefited from the experiences in everyday school life. These experiences may include an active commute to school, engaging in PE classes, increased opportunities for joyful play with other children in a safe and supervised environment.

Brazil's national curriculum (*Base Nacional Curricular Comum* - BNCC) (BRASIL, 2017) proposes that Early Childhood Education institutions expand the universe of children's experiences and skills, having interactions and play as structuring axis for pedagogical practices. In addition, the BNCC proposes that Early Childhood Education must assure learning and development rights for children. These rights consist of exploring movements, active participation of children, and everyday play. Thus, promoting more physical activity opportunities in children's daily lives who attended preschool may be a possible mechanism to explain our results. The results of a cross-sectional study support this hypothesis. Fang et al.(2020) investigated the association between daily step counts and physical fitness in 301 children between 4 and 5 years. They suggested that children with higher daily step counts (measured by accelerometers) than their peers were more likely to have high levels of physical fitness, controlled by age and body composition.

The strength of the analyzes presented in this chapter is mainly due to its large sample of children at the beginning of compulsory schooling in Brazil. In addition, the quasi-experimental design (Separate Pre-Post Samples design) used the opportunity of the cut-off point on the enrollment date to find a group similar in age, which seeks to deal with the threat of maturation. However, the analyzes presented also have limitations. First, SRT's ceiling effect for children in this age group may have limited our ability to observe changes, especially in older age groups who tend to perform better. Second, it was not possible to control the analyzes by the children's body composition, given that we only have the weight and height measurements referring to Wave 1 of the data collection. Third, the longitudinal study's attrition during the first year of preschool might have been selective, possibly leading to bias.

7.5 Conclusion

Compulsory education in Brazil starts at age four – 1st year of preschool. It represents an accelerated and crucial developmental period that is highly influenced by the environment. For example, large-scale studies suggest that participation in the schooling process at this stage of life contributes to cognitive development and academic performance (PEISNER-FEINBERG et al., 1999; SYLVA et al., 2010). In addition, the previous chapter's results (chapter 6) suggested an association between the non-aerobic physical fitness and academic performance of four-to-six-year-old children. Therefore, understanding the effect of preschool on children's motor dimensions can have important implications for education and public health. This chapter analyzed the effect of preschool attendance on the non-aerobic physical fitness of children aged 4.5 to 5 years. The results suggest a small but significant effect of preschool attendance on children's non-aerobic physical fitness and reinforce the importance of investing adequate infrastructure in schools coupled with training and support for the school's staff to improve knowledge about physical activity and motor development benefits. These strategies may enhance children's experimentation and movement opportunities which, in turn, could lead to healthier physical development. More importantly, this effect appears to be more pronounced in children from vulnerable families, suggesting that preschool attendance is associated with more equitable outcomes for children's motor development and physical fitness. This is an important finding considering the large investments municipalities, states and the federal government have made in the past decade to increase preschool attendance in Brazil.

The debate concerning the promotion of opportunities for physical fitness and healthy motor development in childhood is urgent. The evidence from large-scale studies could help policymakers elaborate programs in the educational area and intersectoral policies for early childhood. We must consider that physical fitness is associated with a plethora of health outcomes (JANSSEN; LEBLANC, 2010), mental well-being (LUBANS et al., 2016), and cognitive performance (SANTANA et al., 2017). In addition, the school environment seems to be one of the most suitable places to implement policies aiming to provide better learning opportunities for the most disadvantaged children.

8 Conclusions and implications

The overall aim of this thesis was to analyze children's motor development by focusing on the relationship between non-aerobic physical fitness, cognition, and environmental factors in children between four to six years. The motivations for this thesis were threefold. First, early childhood is a crucial stage of life with accelerated development, reflecting on several future aspects of the individual's life. Second, from a research perspective, in Brazil, we lack knowledge about the influence of the environmental context on children's physical fitness and the relationship between physical fitness and cognition. Third, from an educational and public health perspective, robust evidence that contributes to filling this knowledge gap could help policymakers elaborate programs and policies targeting healthy development for preschool children and reduce social inequalities in education.

This thesis reported several meaningful findings.

Firstly, the Sitting-Rising test performance results, which measured children's non-aerobic physical fitness levels, indicated that most of them could execute the task perfectly, and this result became more prevalent over time. Nonetheless, the SRT could identify children unable to perform those simple motor tasks, possibly indicating some deficit in the components of non-aerobic physical fitness. From a practical perspective, the SRT represents a simple, quick, enjoyable, reliable, and safe tool to screen children's non-aerobic physical fitness.

Secondly, the socioeconomic status of the families, measured through a comprehensive index that encompassed several widely used contextual information, showed no significant association, nor a clear pattern, with children's non-aerobic physical fitness. However, the literature review suggested mixed results in this relationship, especially for young children. In addition, the study's sample only included children from public schools in one Brazilian municipality. This specific sample may have implied a homogeneous group concerning the SES, probably reducing the possibility of identifying differences in this factor.

Thirdly, our results suggest an association between baseline measures of non-aerobic physical fitness and cognitive development, measured by academic performance. These results were significant for mathematics but not for language measures. Moreover, the analyses considering the relationship between changes in non-aerobic physical fitness and cognitive development indicate results in the same direction. For example, children with *persistently low* performance in the SRT showed lower cognitive mathematics scores than those with *persistently high* performance in the two preschool years. Additionally, in the first year of preschool, *decreasing* SRT performance, compared with *persistently high* performance, is related to lower scores in language.

Fourthly, attending preschool positively impacts children's non-aerobic physical fitness in the first year of compulsory education. Most importantly, this positive effect was higher for children from families with low socioeconomic status. Moreover, the existing literature indicates several health-related benefits associated with higher levels of physical fitness and emphasizes a pathway of physical fitness from childhood to adulthood.

8.1 Implications for educational policies

The findings from this thesis add to the knowledge on the association between children's cognitive and motor dimensions and the relationship between environmental factors and non-aerobic physical fitness in preschool children. The large sample size and the longitudinal data provided robust evidence concerning the degree of causal inference. Since the domains of child development present a complex and interrelated structure, the explanations offered in this thesis are grounded in many research areas, such as education, exercise neuroscience, economics, and sports medicine. In addition, the findings add new important insights to educational research, which might provide helpful knowledge to policymakers, educational practice, and for future research.

Early Childhood policies, particularly the expansion of Early Childhood Education, have a crucial role in all dimensions of child development. In Brazil's educational system, since 2009 (BRASIL, 2009, 2013), compulsory education starts at age four, and there are few studies in educational research investigating physical fitness, motor development, or health-related outcomes at this stage of life. Moreover, preschool services are a crucial environmental factor for child development in which children spend a large number of their waking hours. Consequently, schools are in a unique position to encourage and influence healthy behaviors in children. For example, schools can use simple instruments, such as the SRT, to monitor children's motor development, and identify those who might need to increase their physical fitness. This fitness increase can occur through structured activities, such as participation in sports schools and physical education classes, or through a physically active routine outdoor or at home, along with family members.

Some strategies should reinforce the importance of adopting routines aimed at healthy motor development, focusing on increasing children's physical fitness. First, investing in an adequate school infrastructure is crucial for promoting regular play opportunities. This infrastructure might include (but not limited to) attractive playgrounds with challenging but safe equipment, and joyful surface markings (i.e., hopscotch, snakes and ladders, number tracks, alphabet letters, footprint challenges). Suppose it is not feasible in the short term. In that case, one possibility is to map safe outdoor spaces and/or search for partnerships with non-governmental organizations that could offer opportunities to engage in physical activities in a secure environment.

Second, professional development programs should be implemented, providing theoretical and practical physical activity knowledge for the staff. The literature review highlighted that several successful physical activity interventions on children’s motor skills and physical fitness (JONES et al., 2011; PUDER et al., 2011; REILLY et al., 2006) provided training, support, and workshops for the schoolteachers and staff. In addition, these professional development programs could include knowledge about the fitness-cognition relationship and enriched cognitive exercise. These enriched physical activities are based on the framework of embodied cognition which supports the notion that whole-body movements / physical activities both integrated and relevant to a cognitive task are a promising instructional approach (MAVILIDI et al., 2015, 2016, 2017, 2018).

Third, schools should encourage parental involvement in a physically active routine with their children. Preschool children (3-5 years old) should spend at least 180 minutes in a variety of physical activities at any intensity, of which at least 60 minutes is moderate- to high-intensity physical activity, spread throughout the day (BRASIL, 2021; WORLD HEALTH ORGANIZATION, 2019). Parents and caregivers should be aware of benefits of daily physical activity, preferably outdoors and in contact with nature.

Given the deleterious effects of related restrictions due to the pandemic of COVID-19, the Brazilian Society of Pediatrics (*Sociedade Brasileira de Pediatria – SBP*) recently indicated recommendations regarding strengthening families' social bonds, health, and well-being. For example, families should prioritize leisure and social activities outdoors, in open green spaces where children can explore and experience the natural environment such as grass, sand, earth, trees, and plants (SOCIEDADE BRASILEIRA DE PEDIATRIA, 2021). Finally, is worth mentioning that COVID-19 pandemics has resulted in changes to young children's daily routines and habits (physical activity, sedentary screen time and sleep) (FMCSV, 2021; OKELY et al., 2021) along associations with weight gain (WOOLFORD et al., 2021). Therefore, returning to school activities and strengthening the school's importance should be seen as essential elements for recovering child development and well-being.

8.2 Recommendations for future research

This thesis offers the following recommendations for future research that may help improve knowledge about the relationship between environmental factors, physical fitness, and cognition in early childhood.

Brazil's educational system has an unequal distribution of social strata between students, with a higher proportion of children from low socioeconomic status attending public schools. Therefore, research on the association between socioeconomic status and children's physical fitness components should include data from both private and public schools. Including children from a wide range of SES might provide a more heterogeneous sample.

The majority of research investigating the relationship between physical fitness and cognition has been conducted with older children and adolescents. Thus, as early childhood is a critical and rapid stage for human development, more research in preschool populations is needed to better understand the fitness-cognition relationship among different age groups, especially in developing countries such as Brazil. In addition, there is a need to elucidate the mediators and mechanisms responsible for the effects of physical activity and physical fitness on cognition.

Studies investigating "school effects" mainly focused on cognitive outcomes, typically measured by academic performance. Therefore, considering that schools should promote children's development in a holistic perspective, and as cognitive development and physical fitness are interrelated, more research on the effect of school on physical fitness and related constructs is needed.

Most importantly, findings from this thesis and future research should be translated and implemented as educational policies aiming to reduce social inequalities. Society and our children need nothing but the best opportunities for comprehensive development.

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9 Appendix 1: supplementary materials from Chapter 5

Figure 9.1: Boxplot with SRT Wave 1 and SES (quartiles)

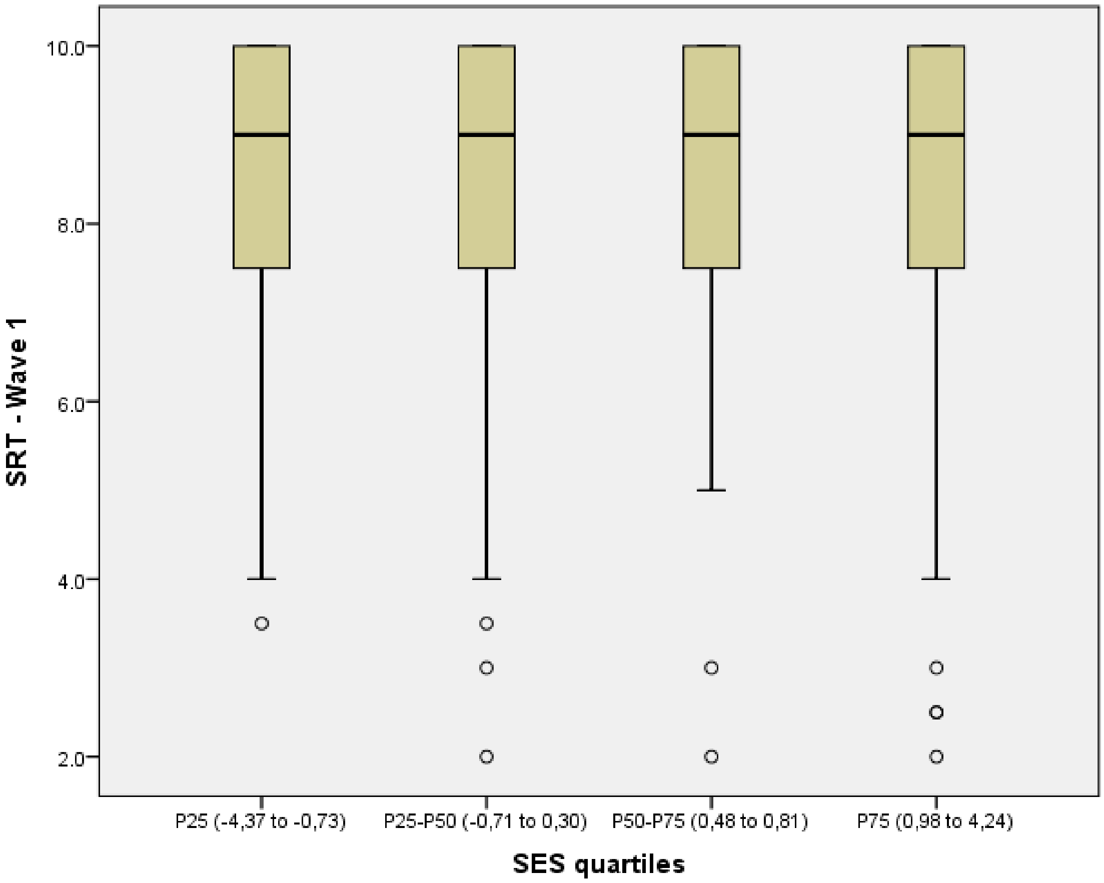


Figure 9.2: Boxplot with SRT Wave 1 and age

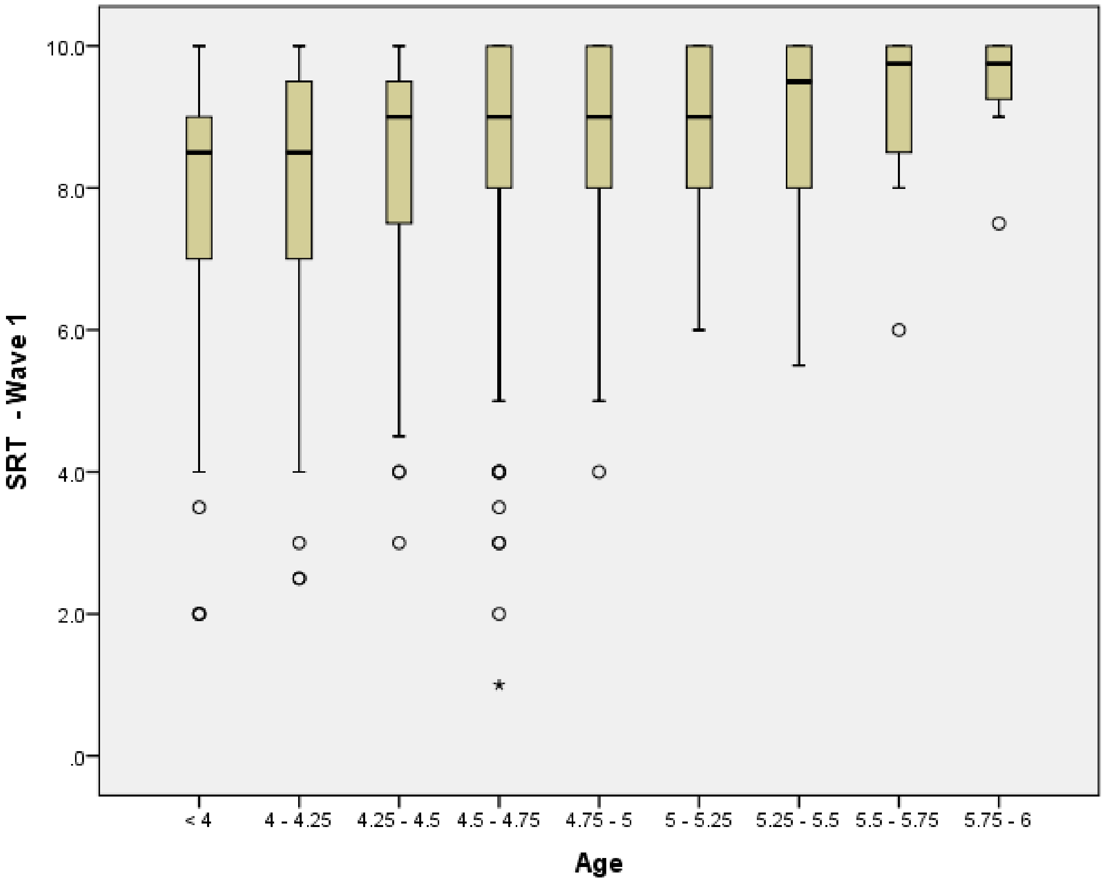


Figure 9.3: Boxplot with SRT Wave 2 and age

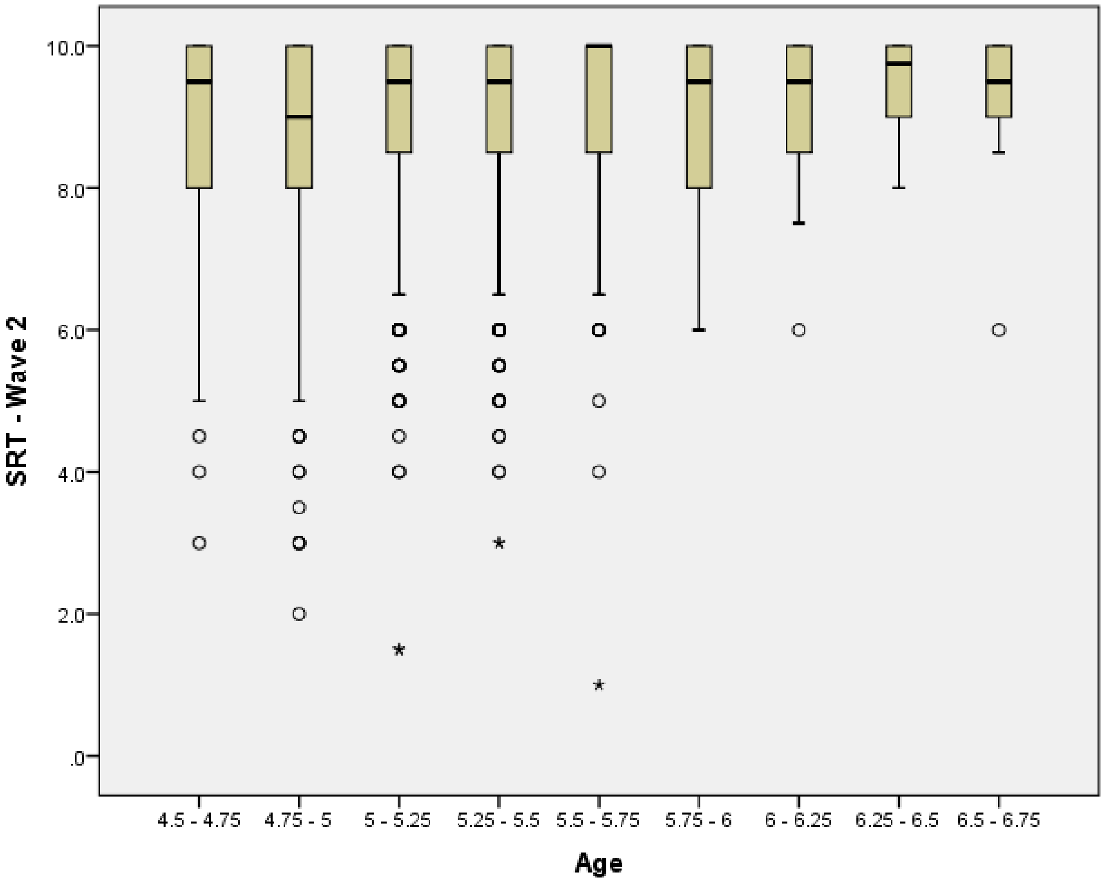
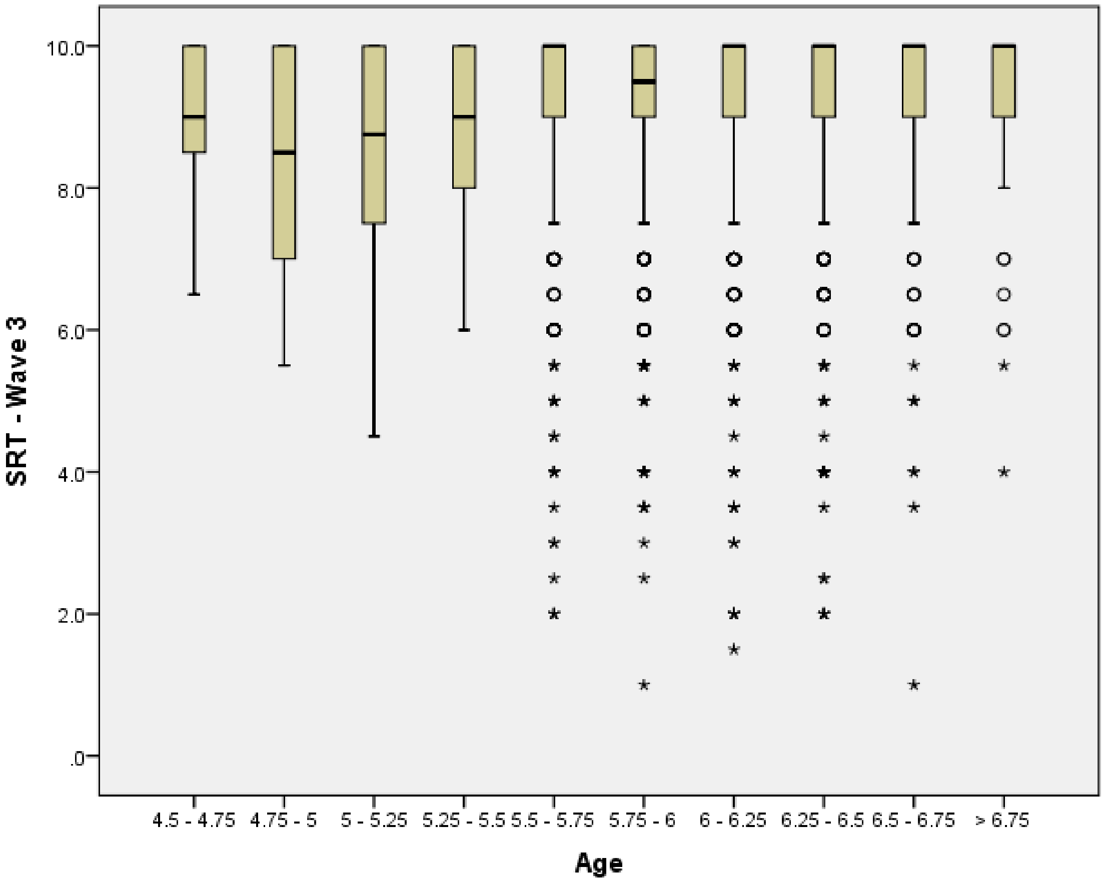


Figure 9.4: Boxplot with SRT Wave 3 and age



10 Appendix 2: supplementary materials from Chapter 6

Figure 10.1: Boxplot with SRT – Wave 1 and Mathematic performance - Wave 2

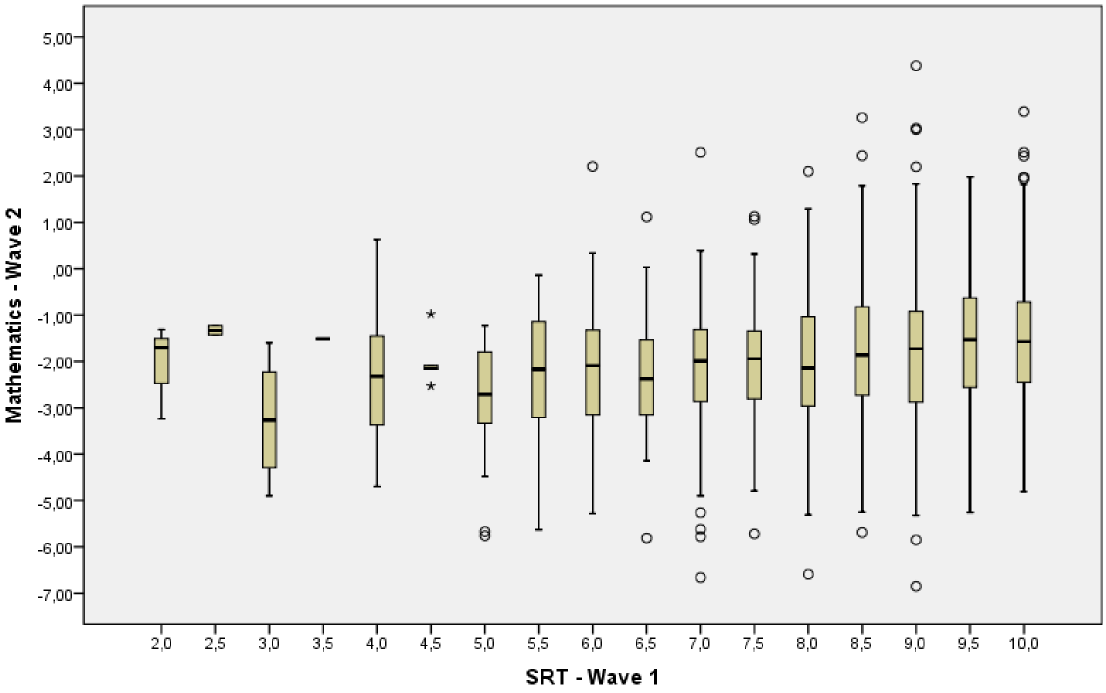


Figure 10.2: Boxplot with SRT – Wave 1 and Language performance - Wave 2

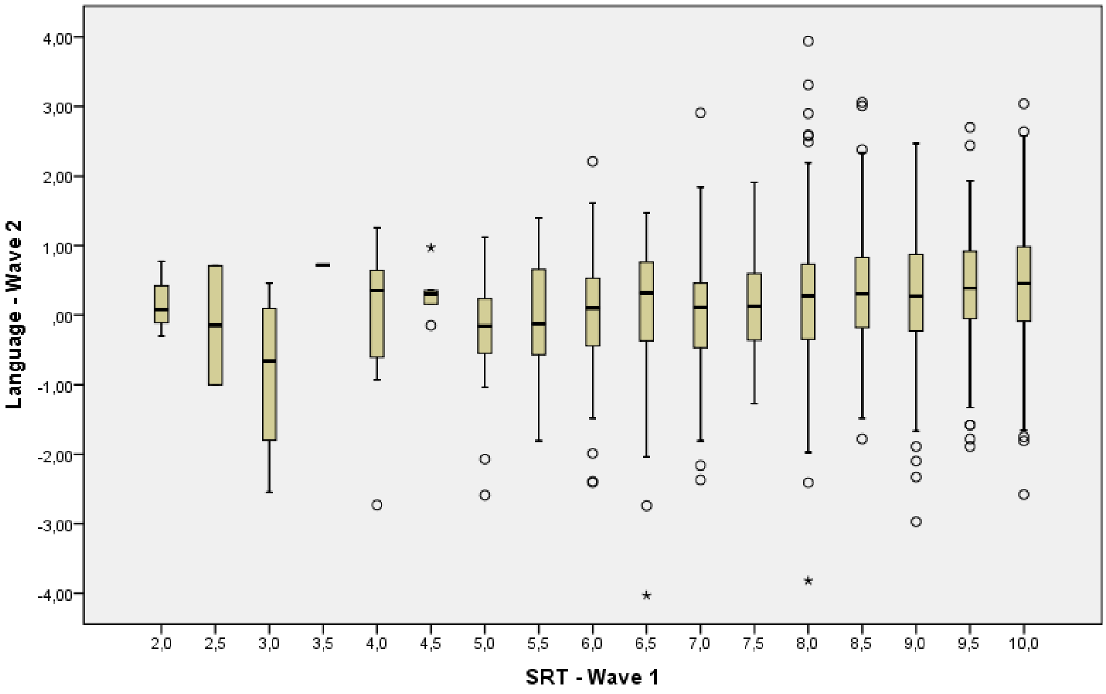


Figure 10.3: Boxplot with SRT – Wave 1 and Mathematic performance - Wave 3

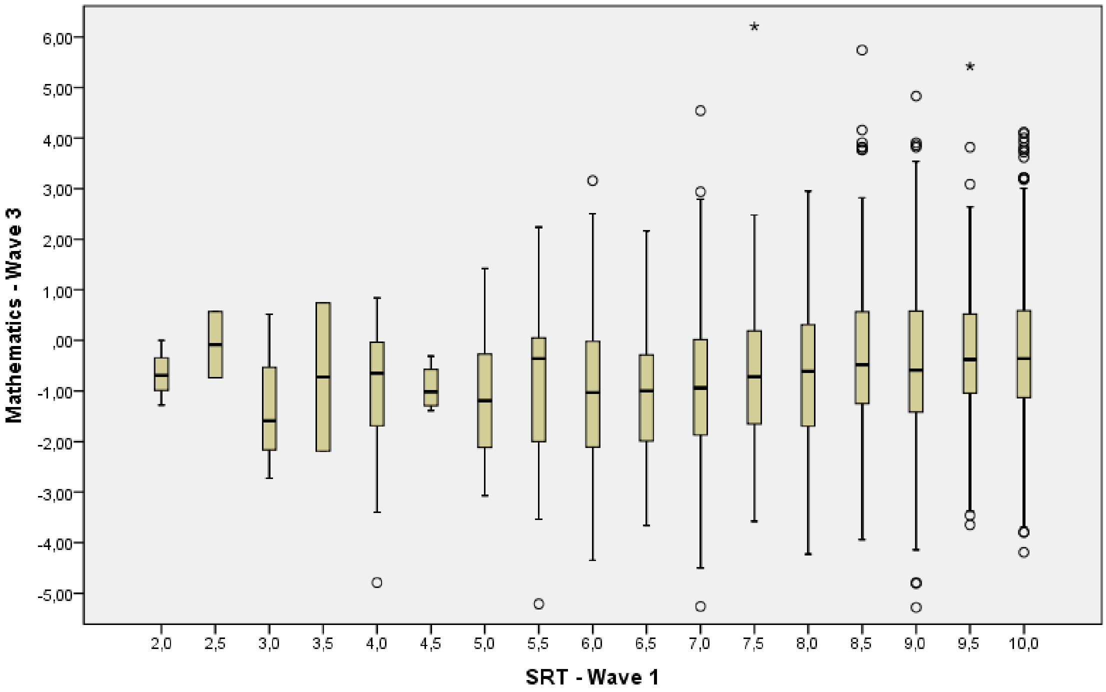


Figure 10.4: Boxplot with SRT – Wave 1 and Language performance - Wave 3

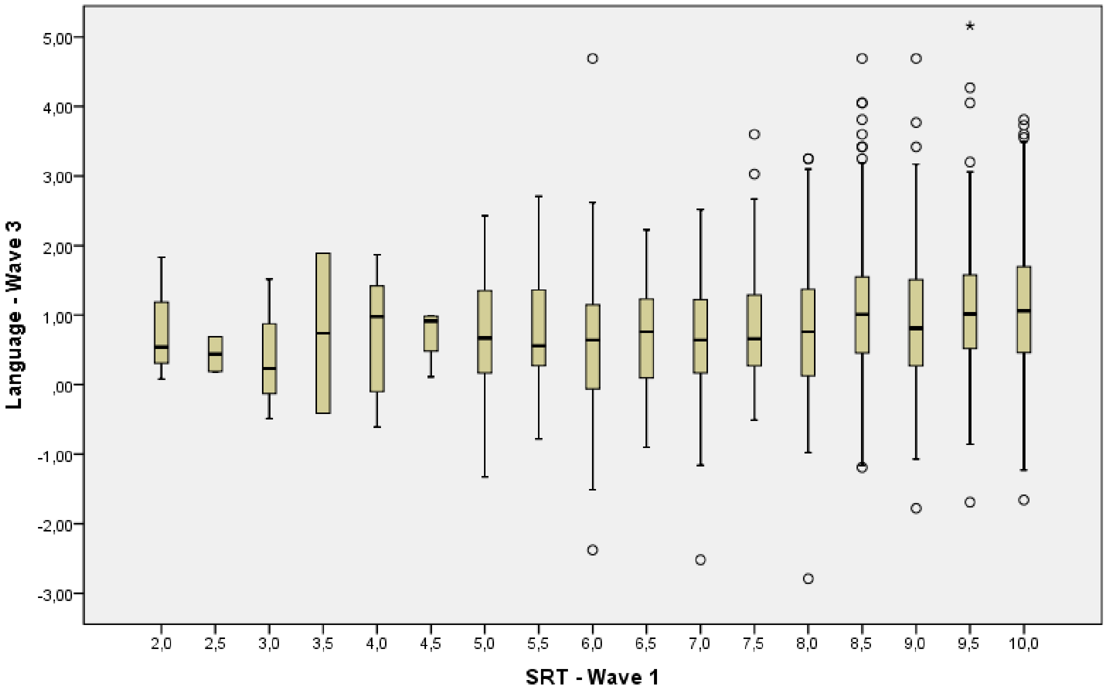


Figure 10.5: Boxplot with SRT change scores (second year of preschool) and Mathematic performance - Wave 3

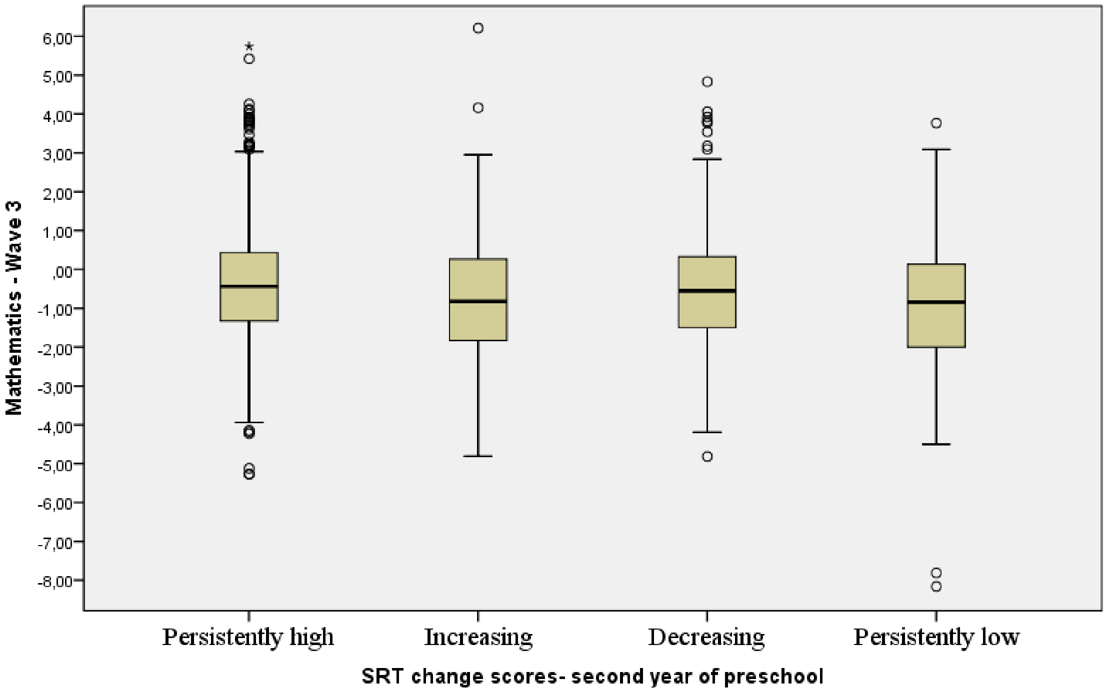


Figure 10.6: Boxplot with SRT change scores (second year of preschool) and Language performance - Wave 3

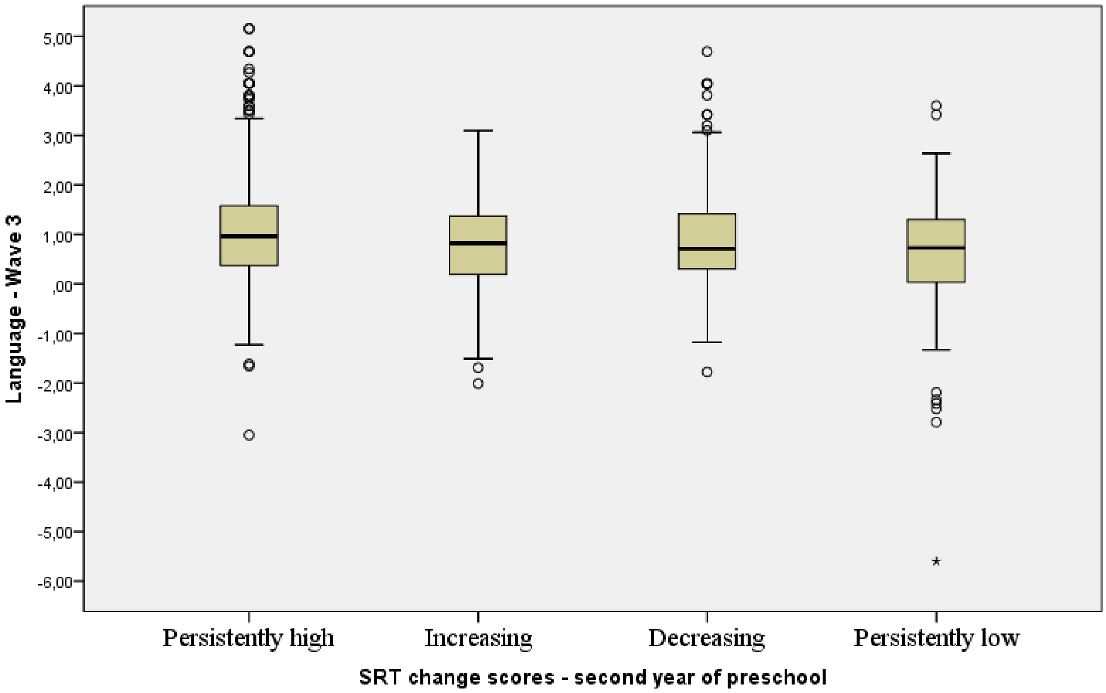


Table 10.1: Hierarchical linear regression models estimating 2nd Wave mathematics measurements (first year of preschool) – Changes in non-aerobic physical fitness with combined categories of decreasing and persistently low

	Model 1	Model 2	Model 3	Model 4
Mathematics				
SRT increasing	**-0,24** (0,08)	-0,05 (0,06)	-0,05 (0,06)	-0,07 (0,06)
SRT *decreasing* and *persistently low*	**-0,32** (0,07)	**-0,15** (0,05)	**-0,15** (0,05)	**-0,14** (0,06)
SEX	0,03 (0,06)	0,04 (0,04)	0,04 (0,04)	0,05 (0,04)
AGE	**0,44** (0,03)	**0,12** (0,02)	**0,13** (0,02)	**0,13** (0,03)
SES	**0,34** (0,03)	**0,12** (0,02)	**0,12** (0,02)	**0,12** (0,02)
SEN	**-0,92** (0,18)	**-0,75** (0,13)	**-0,75** (0,13)	**-0,47** (0,15)
Mathematics (baseline)		**0,95** (0,02)	**0,95** (0,02)	**0,95** (0,02)
Ponderal index				0,02 (0,03)
SES (school)			**0,04** (0,03)	0,03 (0,02)
Explained variance				
school	37%	71%	72%	90%
child	17%	57%	57%	57%
ICC	0.04	0.03	0.03	0.01
Null model				
Var (school)	0.09			
Var (child)	1.77			
ICC	0.05			
N	1956	1956	1956	1606

Note: SRT = Sitting-Rising Test; SEN special educational needs; SES = socioeconomic status; ICC = intraclass correlation coefficient. Significant correlation coefficients in bold ($p < 0.05$).

Table 10.2: Hierarchical linear regression models estimating 2nd Wave language measurements (first year of preschool) – Changes in non-aerobic physical fitness with combined categories of decreasing and persistently low

	Model 1	Model 2	Model 3	Model 4
Language				
SRT increasing	**-0,18** (0,05)	-0,02 (0,04)	-0,02 (0,04)	-0,01 (0,04)
SRT *decreasing* and *persistently low*	**-0,24** (0,04)	**-0,08** (0,03)	**-0,08** (0,03)	**-0,09** (0,04)
SEX	**-0,09** (0,03)	-0,01 (0,03)	-0,01 (0,03)	0 (0,03)
AGE	**0,26** (0,02)	**0,09** (0,02)	**0,09** (0,02)	**0,10** (0,02)
SES	**0,19** (0,02)	**0,06** (0,01)	**0,06** (0,01)	**0,05** (0,01)
SEN	**-0,85** (0,11)	**-0,38** (0,08)	**-0,39** (0,08)	**-0,28** (0,10)
Language (baseline)		**0,54** (0,01)	**0,54** (0,01)	**0,55** (0,02)
Ponderal index				-0,02 (0,02)
SES (school)			**0.04** (0.02)	0,03 (0,02)
Explained variance				
school	25%	51%	58%	66%
child	22%	53%	53%	54%
ICC	0.05	0.05	0.05	0.04
Null model				
Var (school)	0.04			
Var (child)	0.69			
ICC	0.05			
N	1956	1956	1956	1606

Note: SRT = Sitting-Rising Test; SEN special educational needs; SES = socioeconomic status; ICC = intraclass correlation coefficient. Significant correlation coefficients in bold ($p < 0.05$).

Table 10.3: Hierarchical linear regression models estimating 3rd Wave mathematics measurements (second year of preschool) – Changes in non-aerobic physical fitness with combined categories of decreasing and persistently low

	Model 1	Model 2	Model 3
Mathematics			
SRT increasing	**-0,30** (0,09)	-0,08 (0,06)	-0,08 (0,06)
SRT *decreasing* and *persistently low*	**-0,24** (0,08)	-0,05 (0,05)	-0,05 (0,05)
SEX	**0,15** (0,06)	**0,18** (0,04)	**0,18** (0,04)
AGE	**0,47** (0,03)	**0,13** (0,02)	**0,13** (0,02)
SES	**0,31** (0,03)	**0,05** (0,02)	**0,05** (0,02)
SEN	**-1,58** (0,19)	**-0,88** (0,13)	**-0,88** (0,13)
Mathematics (Wave 2)		**1,13** (0,02)	**1,13** (0,02)
SES (school)			**0,05** (0,02)
Explained variance			
school	25%	76%	77%
child	21%	64%	64%
ICC	0.05	0.03	0.03
Null model			
Var (school)	0.12		
Var (child)	2.32		
ICC	0.05		
N	2082	2082	2082

Note: SRT = Sitting-Rising Test; SEN special educational needs; SES = socioeconomic status; ICC = intraclass correlation coefficient. Significant correlation coefficients in bold ($p < 0.05$).

Table 10.4: Hierarchical linear regression models estimating 3rd Wave language measurements (second year of preschool) – Changes in non-aerobic physical fitness with combined categories of decreasing and persistently low

	Model 1	Model 2	Model 3
Language			
SRT increasing	**-0,15** (0,05)	-0,03 (0,04)	-0,03 (0,04)
SRT *decreasing* and *persistently low*	**-0,14** (0,05)	-0,01 (0,03)	-0,01 (0,03)
SEX	**-0,14** (0,04)	**-0,06** (0,03)	**-0,06** (0,03)
AGE	**0,28** (0,02)	**0,08** (0,02)	**0,08** (0,02)
SES	**0,19** (0,02)	**0,05** (0,01)	**0,05** (0,01)
SEN	**-1,10** (0,11)	**-0,35** (0,08)	**-0,35** (0,08)
Language (baseline)		**0,67** (0,01)	**0,67** (0,01)
SES (school)			**0,02** (0,02)
Explained variance			
school	07%	50%	53%
child	18%	60%	60%
ICC	0.09	0.10	0.09
Null model			
Var (school)	0.07		
Var (child)	0.83		
ICC	0.08		
N	2082	2082	2082

Note: SRT = Sitting-Rising Test; SEN special educational needs; SES = socioeconomic status; ICC = intraclass correlation coefficient. Significant correlation coefficients in bold ($p < 0.05$).

Table 10.5: Hierarchical linear regression models estimating 2nd Wave mathematics measurements (first year of preschool) – Changes in non-aerobic physical fitness with combined categories of increasing and decreasing (inconsistent SRT trajectory)

	Model 1	Model 2	Model 3	Model 4
Mathematics				
SRT increasing and decreasing	**-0,22** (0,06)	-0,07 (0,04)	-0,07 (0,04)	-0,08 (0,05)
SRT persistently low	**-0,51** (0,10)	**-0,25** (0,07)	**-0,25** (0,07)	**-0,20** (0,08)
SEX	0,03 (0,06)	0,05 (0,04)	0,05 (0,04)	0,05 (0,04)
AGE	**0,43** (0,03)	**0,12** (0,02)	**0,12** (0,02)	**0,13** (0,03)
SES	**0,34** (0,03)	**0,12** (0,02)	**0,12** (0,02)	**0,12** (0,02)
SEN	**-0,87** (0,18)	**-0,73** (0,13)	**-0,73** (0,13)	**-0,46** (0,15)
Mathematics (baseline)		**0,95** (0,02)	**0,94** (0,02)	**0,95** (0,02)
Ponderal Index				0,01 (0,03)
SES (school)			0,04 (0,03)	0,03 (0,02)
Explained variance				
school	37%	70%	71%	89%
child	18%	57%	58%	57%
ICC	0.04	0.03	0.03	0.01
Null model				
Var (school)	0.09			
Var (child)	1.77			
ICC	0.05			
N	1956	1956	1956	1606

Note: SRT = Sitting-Rising Test; SEN special educational needs; SES = socioeconomic status; ICC = intraclass correlation coefficient. Significant correlation coefficients in bold (p <0.05).

Table 10.6: Hierarchical linear regression models estimating 2nd Wave language measurements (first year of preschool) – Changes in non-aerobic physical fitness with combined categories of increasing and decreasing (inconsistent SRT trajectory)

	Model 1	Model 2	Model 3	Model 4
Language				
SRT increasing and decreasing	**-0,17** (0,04)	**-0,06** (0,03)	**-0,06** (0,03)	**-0,07** (0,03)
SRT persistently low	**-0,34** (0,06)	-0,03 (0,05)	-0,03 (0,05)	-0,01 (0,05)
SEX	**-0,09** (0,03)	-0,01 (0,03)	-0,01 (0,03)	0,00 (0,03)
AGE	**0,26** (0,02)	**0,09** (0,02)	**0,09** (0,02)	**0,10** (0,02)
SES	**0,19** (0,02)	**0,06** (0,01)	**0,06** (0,01)	**0,05** (0,01)
SEN	**-0,82** (0,11)	**-0,40** (0,08)	**-0,40** (0,08)	**-0,30** (0,10)
Language (baseline)		**0,54** (0,02)	**0,54** (0,02)	**0,55** (0,02)
Ponderal Index				-0,01 (0,02)
SES (school)			**0.04** (0.02)	0,03 (0,02)
Explained variance				
school	25%	51%	58%	67%
child	22%	53%	53%	54%
ICC	0.05	0.05	0.05	0.04
Null model				
Var (school)	0.04			
Var (child)	0.69			
ICC	0.05			
N	1956	1956	1956	1606

Note: SRT = Sitting-Rising Test; SEN special educational needs; SES = socioeconomic status; ICC = intraclass correlation coefficient. Significant correlation coefficients in bold (p <0.05).

Table 10.7: Hierarchical linear regression models estimating 3rd Wave mathematics measurements (second year of preschool) – Changes in non-aerobic physical fitness with combined categories of increasing and decreasing (inconsistent SRT trajectory)

	Model 1	Model 2	Model 3
Mathematics			
SRT increasing and decreasing	**-0,22** (0,07)	-0,04 (0,05)	-0,04 (0,05)
SRT persistently low	**-0,41** (0,11)	-0,13 (0,07)	-0,13 (0,07)
SEX	**0,15** (0,06)	**0,18** (0,04)	**0,18** (0,04)
AGE	**0,47** (0,03)	**0,13** (0,02)	**0,13** (0,02)
SES	**0,31** (0,03)	**0,05** (0,02)	**0,05** (0,02)
SEN	**-1,52** (0,19)	**-0,85** (0,13)	**-0,85** (0,13)
Mathematics (Wave 2)		**1,13** (0,02)	**1,12** (0,02)
SES (school)			**0,05** (0,02)
Explained variance			
school	24%	75%	76%
child	21%	64%	64%
ICC	0.05	0.03	0.03
Null model			
Var (school)	0.12		
Var (child)	2.32		
ICC	0.05		
N	2082	2082	2082

Note: SRT = Sitting-Rising Test; SEN special educational needs; SES = socioeconomic status; ICC = intraclass correlation coefficient. Significant correlation coefficients in bold (p <0.05).

Table 10.8: Hierarchical linear regression models estimating 3rd Wave language measurements (second year of preschool) – Changes in non-aerobic physical fitness with combined categories of increasing and decreasing (inconsistent SRT trajectory)

	Model 1	Model 2	Model 3
Language			
SRT increasing and decreasing	**-0,10** (0,04)	-0,01 (0,03)	-0,01 (0,03)
SRT persistently low	**-0,27** (0,07)	-0,06 (0,05)	-0,06 (0,05)
SEX	**-0,14** (0,04)	**-0,06** (0,03)	**-0,06** (0,03)
AGE	**0,28** (0,02)	**0,08** (0,02)	**0,08** (0,02)
SES	**0,19** (0,02)	**0,05** (0,01)	**0,05** (0,01)
SEN	**-1,06** (0,12)	**-0,33** (0,08)	**-0,33** (0,08)
Language (Wave 2)		**0,67** (0,01)	**0,67** (0,01)
SES (school)			0,02 (0,02)
Explained variance			
school	07%	50%	53%
child	18%	60%	60%
ICC	0.09	0.10	0.10
Null model			
Var (school)	0.07		
Var (child)	0.83		
ICC	0.08		
N	2082	2082	2082

Note: SRT = Sitting-Rising Test; SEN special educational needs; SES = socioeconomic status; ICC = intraclass correlation coefficient. Significant correlation coefficients in bold ($p < 0.05$).