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Crescimento, desempenho motor e cognitivo de crianças.
Um estudo longitudinal-misto.

Ana Carolina Rodriguez Reyes

2019

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Ana Carolina Rodriguez Reyes

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Palavras-chaves: CRESCIMENTO; DESEMPENHO MOTOR; DESEMPENHO COGNITIVO; CRIANÇAS.

“O conhecimento torna a alma jovem e diminui a amargura da velhice. Colhe, pois, a sabedoria. Armazena suavidade para o amanhã”.

Leonardo da Vinci

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RESUMO

O propósito principal desta tese foi investigar, numa ótica contextual, as relações entre o crescimento físico, o desempenho motor e o desempenho cognitivo de crianças Portuguesas dos 4 aos 11 anos de idade.

A amostra foi constituída por 411 crianças seguidas longitudinalmente durante 3 anos consecutivos e divididas em 6 coortes etárias. As crianças provêm das 19 escolas do Concelho de Vouzela, centro do país. Foram utilizados procedimentos estandardizados para medir marcadores do crescimento físico, composição corporal, coordenação motora grossa, aptidão física, preferência manual, atividade física, inteligência, da gestação, estatuto socioeconómico e espaços escolares. As análises estatísticas foram realizadas nos *softwares* SPSS, Supermix e STATA.

Em termos genéricos, os resultados mostraram que: (1) no *baseline* as meninas têm maior quantidade de massa gorda; os meninos são mais coordenados, fisicamente aptos e ativos; ~60% das meninas não cumprem as recomendações diárias de atividade física moderada-a-vigorosa e a taxa de cumprimento dos meninos é de 74%; a maioria das escolas está localizada em áreas rurais; todas possuem *playgrounds*, e equipamentos para realizar atividades físicas; (2) as trajetórias do crescimento físico, no peso e no IMC, exibem uma tendência não-linear. O peso ao nascer, o comprimento ao nascer e os ganhos de peso e comprimento até os 18 meses explicaram diferenças nas trajetórias de crescimento físico; (3) as trajetórias do desenvolvimento coordenativo são não-lineares. IMC, a preferência manual e a aptidão física das crianças explicaram diferenças inter-individuais; as meninas tendem a ter um desenvolvimento coordenativo superior; (4) as trajetórias de desenvolvimento da aptidão física exibem uma tendência não-linear favorecendo os meninos; o peso ao nascer influencia a força e a agilidade, o IMC está negativamente associado à agilidade, porém positivamente associado à força; a coordenação motora grossa está associada à aptidão física; em contra partida, a atividade física moderada-a-vigorosa não esteve associada ao desenvolvimento da força estática; (5) as trajetórias de desenvolvimento da inteligência é linear, não há diferenças entre os sexos e a coordenação motora associou-se positivamente com tal desenvolvimento; (6) o estatuto socioeconómico e o contexto escolar não se associaram significativamente com o crescimento físico, coordenação motora grossa, aptidão física e inteligência de crianças Vouzelenses.

Em suma, os resultados sublinharam a importância da abordagem multidisciplinar no estudo do crescimento e desenvolvimento de crianças, a relevância do delineamento longitudinal-misto e necessidade de uma vasta gama informacional. Ademais, é necessária a consideração de preditores fixos e dinâmicos para melhor interpretar de modo mais extenso as diferenças intra-individuais e entre crianças nas suas trajetórias de crescimento e desenvolvimento.

Palavras-chave: crescimento físico, desempenho motor, desempenho cognitivo, delineamento longitudinal, crianças.

ABSTRACT

The main purpose of this thesis was to investigate, in a contextual perspective, the relationships between physical growth and both motor, and cognitive performances of Portuguese children from 4 to 11 years old.

The sample was comprised of 411 children from the 19 schools of Vouzela municipality, located at the center of the country, which were divided into 6 age cohorts and longitudinally followed for 3 consecutive years. Standardized procedures were used to measure indicators of physical growth, body composition, gross motor coordination, physical fitness, manual preference, physical activity, intelligence, gestation, socioeconomic status and school content. Statistical analyses were performed in SPSS, Supermix and STATA software.

In general, results showed that: (1) at baseline, girls had more body fat mass; boys were more coordinated, physically fit and active; ~60% of girls did not meet the daily recommendations of moderate-to-vigorous physical activity, while the boys' were 74%; most of the schools were located in rural areas; all had playgrounds, and equipment for physical activity; (2) physical growth trajectories, both in weight and BMI, exhibited a non-linear trend. Birth weight, birth length, and gains on weight and length up to 18 months explained differences in physical growth trajectories; (3) coordinative development trajectories were non-linear. BMI, manual preference and physical fitness of children explained inter-individual differences; girls tended to have higher coordinative development; (4) physical fitness development trajectories exhibited a non-linear tendency favoring boys; birth weight influenced strength and agility, BMI was negatively associated with agility, but positively associated with strength; gross motor coordination was associated with physical fitness; in contrast, moderate-to-vigorous physical activity was not associated with the development of static force; (5) developmental trajectories of intelligence were linear, no differences between the sexes were found, and motor coordination was positively associated with such development; (6) socioeconomic status and school context were not significantly associated with physical growth, gross motor coordination, physical fitness, and intelligence of Vouzela children.

In summary, these results showed the relevance of the multidisciplinary approach in the study of children's growth and development, the importance of the longitudinal-mixed design and the need for a wide informational range. In addition, it was necessary to consider fixed and dynamic predictors to better interpret intra-individual differences and between children in their growth and development trajectories more extensively.

Key-words: physical growth, motor performance, cognitive performance, longitudinal design, children.

LISTA DE ABREVIATURAS E SÍMBOLOS

AAHPERD	American Alliance for Health, Physical Education, Recreation and Dance
ALPASC	Avon Longitudinal Study of Parents and Children
ANCOVA	Analysis of Covariance
ACeS	Agrupamentos de Centros de Saúde
AF	Atividade física
ApTF	Aptidão física
BFM	Body fat mass
BMI	Body mass index
BW	Birth weight
CATCH	Coordination and Activity Tracking in Children study
CE	Cohort effect
CE_C2_1	Overlapping effect of cohort 2 on 1
CE_C3_2	Overlapping effect of cohort 3 on 2
CE_C4_3	Overlapping effect of cohort 4 on 3
CE_C5_4	Overlapping effect of cohort 5 on 4
CE_C6_5	Overlapping effect of cohort 6 on 5
CEBQ	Chilren´s Eating Behavior Questionnaire
cm	Centímetros / Centimeters
CI	Confidence Interval
CM	Coordenação motora
CMG	Coordenação motora grossa
day^{-1}	Per day
DBP	Diastolic blood pressure
DCD	Development coordination disorder
DHQ	The Dutch Handedness Questionnaire
DM	Desenvolvimento motor
EB	Ensino básico
EF	Educação física
ETM	Erro técnico de medida

EUA	Estados Unidos da América
F	Female
FADE-UP	Faculdade de Desporto da Universidade do Porto
g	Gramas
GLU	Glucose
GMC	Gross motor coordination
GMDC-Vouzela Study	Growth, Motor Development and Cognition Study
HDL-C	High-density lipoprotein-cholesterol
HH	Hopping for height
HLM	Hierarquical Linear Modeling
HME	Habilidades motoras específicas
HMF	Habilidades motoras fundamentais
IC	Intervalo de confiança
i.e.	Isto é
IDEFICS	Identification and prevention of dietary- and lifestyle-induced health effects in children and infants
IQ	Intelligence quotient
ISCOLE	International Study of Childhood Obesity, Lifestyle and the Environment
JS	Jumping sideways
IMC	Índice de massa corporal
kg	Quilograma / Kilogram
Km^2	Quilometros quadrados
KTK	KöperkoordinationsTest für Kinder
LB	Length at birth
LG	Length gains
LH	Left hand
LHP	Left hand preference
M	Male
m	Metros / Meters
m^2	Metros quadrado / Square meters
M_1	Modelo 1
M_2	Modelo 2

M_3	Modelo 3
M_4	Modelo 4
MABC-2	Movement Battery for Children - 2
MHMN	Modelação hierárquica ou multinível
min	Minutos / Minuts
MS	Moving sideways
MP	Manual preference
MVPA	Moderate-to-vigorous physical activity
N / n	Amostra / Sample size
ns	Non statically significant
NASPSPA	North American Society for the Psychology of Sport and Physical Activity
OMS	Organização Mundial de Saúde
OP	Ocular preference
p / P	Valor de prova
PA	Physical activity
PE	Pysical education
PIQ	Performance intelligence quotient
PF	Physical fitness
PNS	Planos Nacionais de Saúde
PP	Pedal preference
RH	Right hand
RHP	Right hand preference
s	Segundos/ Seconds
SBP	Systolic blood pressure
SD	Standard deviation
SES	Socioeconomic status
SPSS	Statistical Package for the Social Sciences
TGMC/GMCS	Total gross motor coordination
TRI	Triglycerides
WB	Walking backwards
WC	Waist circumference
WG	Weight gains

WHO	World Health Organization
WISC-III	Wechsler Intelligence Scale for Children – 3rd edition
year^{-1}	Per year
yrs	years
€	Euros
χ^2	Chi-square
η_p^2	Eta squared
ϕ	Phi coefficient
β	Beta (coeficiente de regressão)
σ^2	Variância
<	Menor
>	Maior
≤	Menor ou igual
≥	Maior ou igual
%	Percentual
~ / ≈	Aproximadamente
=	Igual
+	Positivo / Posiive
-	Negativo / Negative
±	Mais ou menos

CAPÍTULO I

INTRODUÇÃO GERAL e
ESTRUTURA da TESE

INTRODUÇÃO GERAL

O desenvolvimento é, essencialmente, um dos principais processos que marca, indelevelmente, a vida do ser humano (Lerner, 1986). Ademais, expressa-se por uma forte plasticidade fenotípica (Pigliucci, 2001), i.e., o resultado da resposta adaptativa individual às mutações do contexto em que o indivíduo constrói a sua história de vida (Moran, 2008). Há quem refira um conjunto de facetas do desenvolvimento humano, mormente o dinamismo da sua continuidade, aditividade/não-aditividade e sequencialidade desde a conceção até à morte (Lerner, 1986). Esta *big and gross picture* resulta da complexa teia relacional, não-linear, entre o património genético individual e as caraterísticas do seu ambiente físico e construído (Bodmer & McKie, 1997; Malina, Bouchard, & Bar-Or, 2004).

É hoje inquestionável que nas duas primeiras décadas de vida ocorrem algumas das mudanças mais marcantes e importantes no crescimento físico e desenvolvimento humano, i.e., existe numa janela temporal basilar para a formação do indivíduo (Ehrlich, 2000; Gabbard, 2014). Nesta ocorrem processos de enorme complexidade nos domínios físico, motor, cognitivo, afetivo e social em constante inter-relação e que revelam o(s) modo(s) como a criança e o adolescente se ajustam ao seu meio (Gallahue, Ozmun, & Goodway, 2013). Num certo sentido é sobre esta janela que os especialistas do Desenvolvimento Motor costumam debruçar-se (Gallahue et al., 2013; Haywood & Getchell, 2010; Malina et al., 2004).

Especificamente no domínio motor, as crianças têm uma extraordinária capacidade plástica para aprender e desenvolver uma variedade de habilidades motoras fundamentais (HMF), construindo, assim, um repertório motor diversificado, de complexidade crescente, base para a aquisição de habilidades motoras mais específicas do rico património motor culturalmente referenciado da humanidade (Haywood, 1986; Haywood & Getchell, 2010). De facto, do período da pré-escola à entrada no 2º Ciclo do Ensino Básico (EB) ocorrem as importantes transições entre a fase de desenvolvimento de HMF para a fase de combinação dessas HMF em padrões crescentemente complexos, até se chegar à fase das habilidades motoras especializadas (HME) (Haubenstricker, Branta, & Seefeldt, 1983; Roberton, 1978). Decorre, necessariamente, daqui que o desenvolvimento das HMF exige prática orientada e sistemática (Clark, 2007).

Apesar de existirem marcos ou estádios motores temporalmente referenciados que balizam as distintas fases que permitem a aquisição da posição bípede e a marcha independente (Bayley, 1969; Largo, Molinari, Weber, Pinto, & Duc, 1985; Shirley, 1963), e o mesmo ocorrer na aquisição e desenvolvimento das HMF (Gallahue et al., 2013; Wickstrom, 1983), o caráter emergente da expressão dos níveis de proficiência é o da variação intra e inter-individual.

Historicamente, alguns dos manuais mais representativos do Desenvolvimento Motor produzidos nos Estados Unidos da América (EUA) (i.e, Gabbard, 2014; Gallahue et al., 2013; Haywood, 1986; Haywood & Getchell, 2010; Malina et al., 2004; Payne & Isaacs, 2008) dedicam, também, uma especial atenção em colocar o desafio investigativo do Desenvolvimento Motor sob uma perspetiva de *lifespan.* Essa perspetiva reveste-se de enorme significado para o estudo do desenvolvimento, visto que exige, necessariamente, informação longitudinal. Na ótica desenvolvimentista, o estudo da mudança exige um delineamento longitudinal envolvendo a monitorização, descrição, análise e interpretação de determinadas variáveis nos mesmos indivíduos (i.e., em crianças no nosso caso), ao longo de um dado período de tempo com intervalos específicos e (aparentemente) equidistantes (Baltes & Nesselroade, 1979; Taris, 2000). Decorrente desta perspetiva, os propósitos fundamentais dos estudos do desenvolvimento são: (1) identificar a mudança intra-individual; (2) identificar as diferenças ou similaridades inter-individuais na mudança intra-individual; (3) analisar as relações entre comportamentos intra-individuais observados durante a mudança; e (4) analisar a influência de preditores da mudança intra-individual e das diferenças inter-individuais (Baltes & Nesselroade, 1979).

Apesar do delineamento longitudinal puro “clássico” ser considerado o mais poderoso e eficiente em pesquisas sobre o crescimento físico, desenvolvimento motor e cognitivo (Papalia, Olds, & Feldman, 2009) ele contém, adstrito, um conjunto de limitações à sua utilização, de entre os quais destacamos: (1) custos relativamente elevados, (2) logística complexa para a recolha da informação, (3) dimensão amostral relativamente elevada, (4) *drop-out*, (5) manutenção ou substituição adequada da equipa de avaliadores, e (6) a demora em produzir resultados publicáveis (Gallahue et al., 2013; Malina, 2009; Matton et al., 2007). Uma alternativa a este tipo de delineamento, com custos mais reduzidos e de menor temporalidade, é o delineamento longitudinal-misto ou acelerado, que combina os aspetos mais importantes dos delineamentos transversal e longitudinal puro (Duncan & Duncan, 2012). Proposto inicialmente por Bell (1953), este tipo de delineamento carateriza-se por ter múltiplas coortes de indivíduos com sobreposição etária (Duncan & Duncan, 2012). Dentre as suas vantagens, destacam-se (1) o período relativamente mais curto na recolha da informação, (2) redução de custos, 3) redução do *drop-out* amostral, e (4) a possibilidade de estimar a magnitude dos efeitos da idade, coorte e período de medição na análise da mudança (Bell, 1954; Van Mechelen & Mellenbergh, 1997). Este delineamento tem sido utilizado com frequência na pesquisa em Desenvolvimento Motor no Brasil (Basso et al., 2009; Biassio, Matsudo, & Matsudo, 2008), bem como em Portugal (Freitas et al., 2002; Maia, 2010, 2015).

Não obstante a existência de pelo menos dois documentos centrais que procuraram inventariar, do ponto de vista histórico, momentos fundamentais do estudo em Desenvolvimento Motor (Clark, 2017; Robinson, 2018), parece ser mais ou menos consensual a não existência de uma teoria formal do Desenvolvimento Motor. Contudo, tal ausência não tem limitado a pesquisa e o seu impacto educacional e social. Historicamente, o crescimento e desenvolvimento motor de crianças foram explicados a partir de uma base essencialmente biológico-maturacional (Gesell, 1954; Salkind, 1981). Mais recentemente, se contrapôs a essa explicação, uma orientação ecológica fundada na abordagem dos sistemas dinâmicos particularmente nas questões do controle motor e desenvolvimento motor nos primeiros anos de vida (Thelen & Smith, 1996). Nos dias que decorrem, estão presentes na literatura produzida no domínio do Desenvolvimento Motor três abordagens que permitem entradas distintas na “coisa desenvolvimentista”: (1) o modelo de Newell (1986), (2) o modelo de Stodden et al. (2008), e (3) a teoria bio-ecológica do Desenvolvimento Humano proposta por Bronfenbrenner (Bronfenbrenner, 1977, 1979). Apesar de nunca terem sido formalmente testados em toda a sua extensão e implicações, pelo menos até ao presente e até onde vai o nosso conhecimento, essas abordagens têm sido de enorme utilidade para os pesquisadores.

Foulkes et al. (2015) estudaram os níveis de proficiência na expressão das HMF em crianças pré-escolares com baixo nível socioeconómico recorrendo ao modelo de Newell (1986) que propõe que o desenvolvimento motor resulta da interação de três restrições (*constraints*), quais sejam o organismo, o ambiente e a tarefa. O nível socioecónomico seria uma restrição ao desempenho proficiente, ou não, das crianças. Por exemplo, Barnett et al. (2009) consideram o efeito da prática como uma restrição potencializadora no processo de desenvolvimento a “longo prazo” na proficiência em HMF (i.e., pegar, chutar, arremessar). Estes autores ressaltaram a importância do controle de alguns preditores [i.e., apoio dos pais, atividade física (AF) dos irmãos e oportunidades de exercícios] no desempenho de HMF uma vez que as crianças e adolescentes podem ser influenciadas, também, pelas restrições da tarefa e do indivíduo (ver Figura 1). Portanto, considerando o modelo, a dinâmica da mudança nas restrições pode tanto potencializar como limitar o processo de desenvolvimento (Newell, 1986).

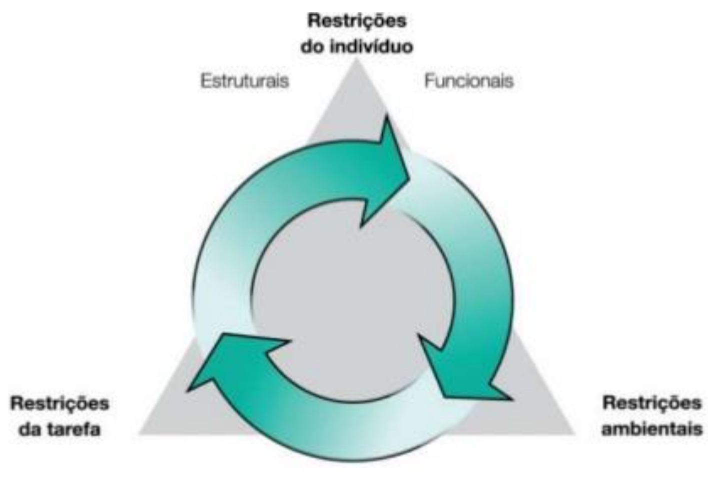

Figura 1. Modelo das restrições de Newell (1986)

Uma perspetiva mais recente designada de modelo de Stodden (Stodden et al. (2008) tem sido bastante utilizada em pesquisa com crianças (Cairney, Dudley, Kwan, Bulten, & Kriellaars, 2019; Jaakkola et al., 2019; Palmer, Chinn, & Robinson, 2019; Robinson et al., 2015; Utesch, Bardid, Büsch, & Strauss, 2019). Esta perspetiva trata, essencialmente, da importância do desenvolvimento da competência motora[1] na promoção de trajetórias positivas ou negativas de AF e estatuto ponderal, considerando a aptidão física (ApTF) e a competência motora percebida como possíveis mediadores (Robinson et al., 2015) (Figura 2). Jaakkola et al. (2019), por exemplo, investigaram as relações recíprocas da competência motora, perceção da competência motora, ApTF relacionada com a saúde e medidas objetivas de AF de crianças. Por seu lado, Palmer et al. (2019) examinaram as alterações na HMF e na AF eliciadas por uma intervenção de HMF por 5 semanas (600 minutos) em crianças pré-escolares.

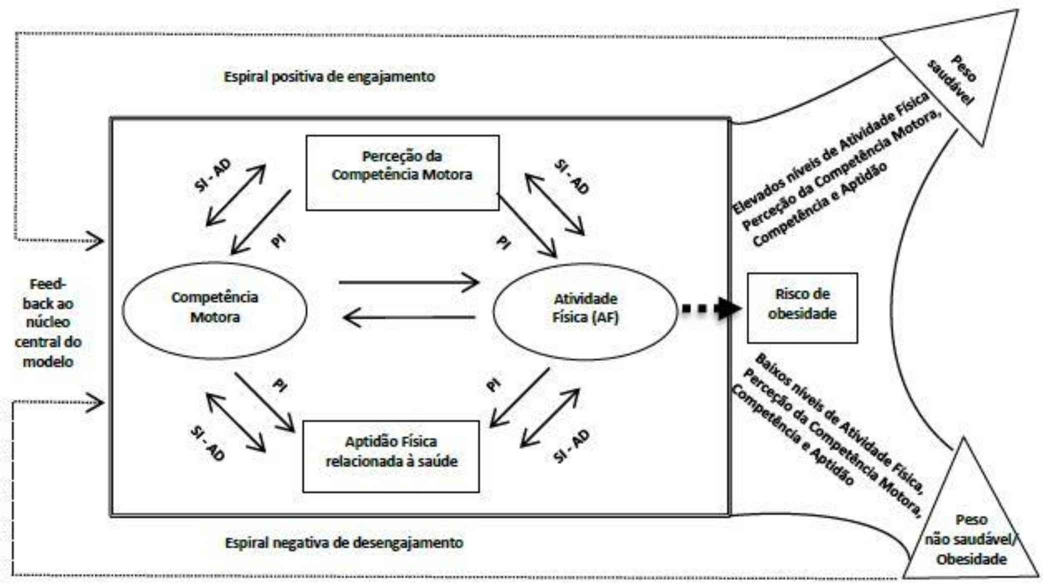

Figura 2. Modelo sinergista da competência motora e da atividade física de Stodden et al. (2008).

Ademais, a teoria bio-ecológica do Desenvolvimento Humano de Bronfenbrenner (1977, 1979) tem recebido, também, algum destaque entre

[1]Termo global empregado para refletir várias terminologias utilizadas na literatura (proficiência motora, desempenho motor, habilidade motora, coordenação motora, etc.) para descrever o movimento (Robinson et al.).

pesquisadores do Desenvolvimento Motor (Gabbard, 2014; Gallahue et al., 2013; Krebs, 1995a).

Esta teoria engloba quatro domínios/níveis fundamentais do desenvolvimento - o processo, a pessoa, o contexto, e o tempo (Bronfenbrenner & Ceci, 1994; Bronfenbrenner & Morris, 2006) (ver Figura 3). Um dos principais divulgadores desta teoria em língua portuguesa foi o saudoso Professor Ruy Jornada Krebs (Krebs, 1995a, 1995b, 1997; Krebs & Ferreira Neto, 2007) que a usou para interpretar aspetos do desenvolvimento motor na infância e na adolescência. Um exemplo recente salientou a urgência em pesquisar, simultaneamente, as caraterísticas a nível do indivíduo e da escola na variabilidade do desempenho em diferentes provas de ApTF de crianças (Santos et al., 2018).

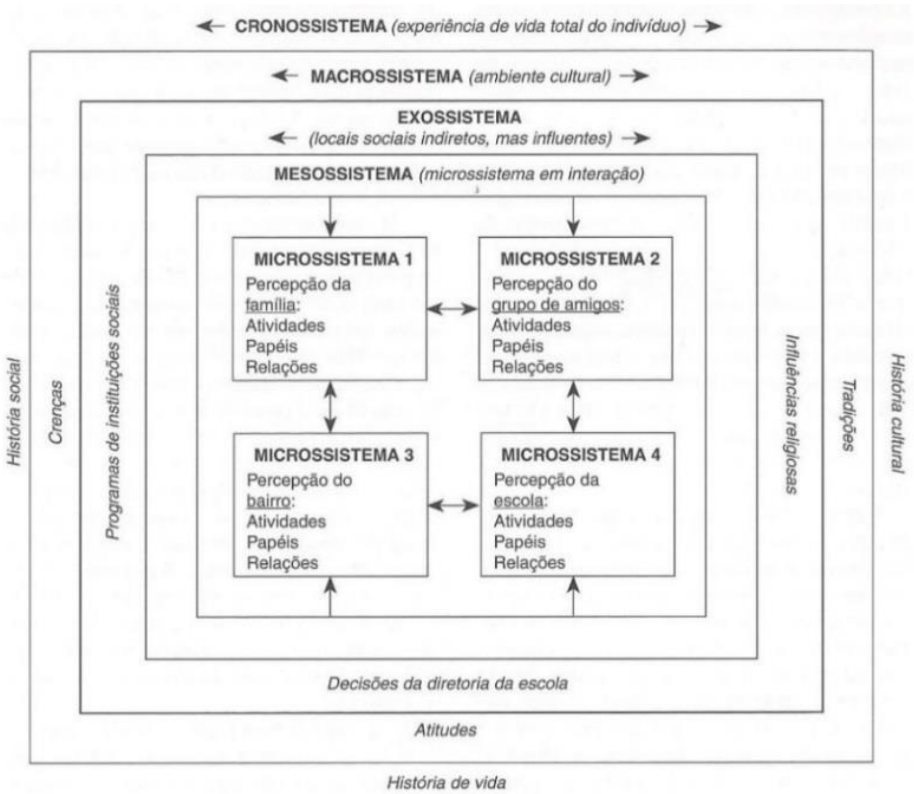

Figura 3. Conceituação da teoria bio-ecológica do Desenvolvimento Humano de Bronfenbrenner (adaptado por Gallahue et al. 2013).

A recente reunião anual (2017) da *North American Society for the Psychology of Sport and Physical Activity (NASPSPA)* foi marcada não só pela celebração dos seus 50 anos mas também por dois debates essenciais: o primeiro sobre a importância e implicações dos estudos longitudinais no vasto território do Desenvolvimento Motor, e o segundo acerca da pesquisa contemporânea e orientações futuras. Por exemplo, Clark (2017) elaborou sobre as várias "camadas" da pesquisa em Desenvolvimento Motor numa ótica histórica, sugerindo que a investigação no século XXI poderá orientar-se para as neurociências e ou para o papel da AF e da saúde, particularmente no que concerne à obesidade e fatores de risco cardiovascular. Robinson (2018) sugere, também, que a "viagem futura" do Desenvolvimento Motor pode trilhar novos desafios, designadamente: (i) como abordar as necessidades motoras de populações especiais? (ii) que complexidades ocorrem no cérebro durante a realização de movimentos simples e complexos? (iii) como é que o nosso ambiente físico e construído afeta o comportamento motor durante fases relevantes do desenvolvimento da criança e do adolescente? (iv) Qual é o efeito, os mecanismos e as implicações do movimento ao longo da vida e em várias facetas da saúde? Contudo, a autora aponta a ausência de dados empíricos que evidenciem, com solidez, o curso das trajetórias modais, a extensão da variabilidade inter-individual e as influências de conjuntos de preditores em distintas manifestações do desempenho motor e da competência motora.

O crescimento físico é um processo de aumento do corpo e das suas partes, com expressões notórias na proporcionalidade somática e composição corporal (Malina et al., 2004). Dois dos principais marcadores antropométricos do crescimento de crianças e jovens são a altura e peso e, consequentemente, o índice de massa corporal (IMC) (WHO, 1995) bem assinalados por fatores genéticos e ambientais (Thomis & Towne, 2006; Visscher, 2008; Wells & Stock, 2011). Ademais, "agentes" importantes a considerar na pesquisa sobre o crescimento físico são aqueles ralativos aos perinatais, podendo estes induzir consequências a longo prazo na infância, adolescência e até na fase adulta (Hack et al., 2003; Linsell et al., 2019; Ong & Loos, 2006). O peso ao nascer, comprimento ao nascer e os ganhos de altura e peso até os dois primeiros anos de vida têm sido reportados como fatores relevantes (Rogers et al., 2006; Wells, Chomtho, & Fewtrell, 2007). Na revisão sistemática de Moreira, Magalhães & Alves (2014) foi possível concluir que crianças prematuras são mais suscetíveis de comprometimento no seu desenvolvimento motor, comportamento e no desempenho académico quando comparados com o desenvolvimento de crianças nascidas a termo. Barker, Osmond, Forsén, Kajantie & Eriksson (2005), por exemplo, indicaram que o baixo peso ao nascer estava associado ao crescimento físico mais rápido de crianças, ao acúmulo de gordura, à hipertensão arterial durante a adolescência e ao risco de doenças metabólicas na idade adulta. Além disso, ganhos rápidos de peso na infância têm sido associados ao aumento do risco de obesidade tanto na infância quanto em idade adulta (Baidal et al., 2016; Karaolis-Danckert et al., 2006).

O desempenho motor, mais especificamente uma forma da sua expressão designada por competência motora (Robinson et al. 2015), está relacionado com a eficiência com que as crianças desempenham suas atividades diárias (Hands, 2008) e a expressão da coordenação motora grossa (CMG) é reconhecida ser uma das suas principais facetas (Robinson et al., 2015). Por exemplo, crianças mais coordenadas tendem a ser mais aptas e mais ativas (Fransen et al., 2012; Graf et al., 2004), enquanto aquelas com excesso de peso e obesidade tendem a ser menos coordenadas (D'Hondt et al., 2013). Crianças destrímanas tendem a ser mais coordenadas que as sinistrómanas (Gabbard, Hart, & Gentry, 1995) e crianças com baixo peso à nascença mostram comprometimento no seu desenvolvimento motor, especialmente na coordenação motora (Brown, Burns, Watter, Gibbons, & Gray, 2015). Já a ApTF das crianças encontra-se positivamente associada com os seus níveis de AF (Eberline, Judge, Walsh, & Hensley, 2018), CMG (de Chaves et al., 2016), e peso ao nascer (Jantunen et al., 2018).

Idade, sexo e estatuto socioeconómico desempenham papéis importantes na expressão dos níveis de CMG (Barnett et al., 2016) e ApTF de crianças (Klein, Fröhlich, Pieter, & Emrich, 2016). Contudo, por mais que seja enfatizada a urgência de informação longitudinal acerca de diferentes fatias do desempenho motor de crianças e de possíveis preditores que possam ajudar na interpretação das diferenças inter-individuais e nas mudanças intra-individuais, o fato é que os dados disponíveis são relativamente escassos. Por exemplo, informação longitudinal sobre a CMG utilizando a bateria de testes *Körperkoordinationstest für Kinder* (Kiphard & Schilling, 1974) é ainda escassa e originária, principalmente, da Alemanha, Bélgica e Portugal (Antunes et al., 2016; Vandorpe et al., 2012; Willimczik, 1980). Adicionalmente, também é relativamente rara informação longitudinal das mudanças que ocorrem na ApTF de crianças, principalmente em pré-escolares e crianças do 1º Ciclo do EB (Bai, Saint-Maurice, & Welk, 2017; Rodrigues, Stodden, & Lopes, 2016; Ruedl et al., 2018).

No início da década de 90 os EUA declararam esta como a "década do cérebro", e uma parte substancial da pesquisa em Desenvolvimento Motor começou a focar a sua atenção nas relações entre os domínios motor e cognitivo (Clark, 2017). Jean Piaget foi, inquestionavelmente, um dos principais arquitetos da teoria dos estágios/períodos cognitivos (sensório motor, pré-operacional, operações concretas, operações formais) com ênfase nos processos mentais (Piaget, 1977, 2003; Piaget & Cook, 1952). Estudos contemporâneos focam o seu olhar num domínio designado por Neurociência Motora do Desenvolvimento (Diamond, 2000; Pangelinan, Kagerer, Momen, Hatfield, & Clark, 2010; Pangelinan et al., 2011). Ademais, a competência motora das crianças tem sido pensada como um importante mediador do seu envolvimento em atividades físicas diversificadas (Barnett, Van Beurden, Morgan, Brooks, & Beard, 2008; Williams et al., 2008), bem como tendo uma interferência direta na sua saúde das crianças. Segundo Clark (2017), o cruzamento de todo este novelo relacional pode interferir no desempenho cognitivo e académico de crianças (Donnelly et al., 2016; Haapala, 2012, 2013).

Aspetos do desenvolvimento cognitivo, mais especificamente da inteligência de crianças, podem ser associados a diferentes preditores descritos em pesquisa de natureza transversal (Bakhiet et al., 2017; Von Stumm & Plomin, 2015) bem como a revisões sistemáticas (Ferrero, West, & Vadillo, 2017; Ntolka & Papadatou-Pastou, 2018). Por exemplo, tem sido sugerido que no período da infância não há diferenças estatisticamente significativas entre meninos e meninas no que respeita ao seu quociente de inteligência (Lynn & Kanazawa, 2011). Ademais, a obesidade poderá estar negativamente associada ao desempenho inteligente num conjunto variado de tarefas (Sandjaja et al., 2013). Crianças com níveis mais elevados de CMG e fisicamente ativas tendem a expressar níveis mais elevados de inteligência (Fernandes et al., 2016; Tomporowski, Davis, Miller, & Naglieri, 2008). Adicionalmente, a preferência manual e o estatuto socioeconómico parecem desempenhar um papel importante no modo como as crianças expressam sua inteligência (Hanscombe et al., 2012; Ntolka & Papadatou-Pastou, 2018). Apesar de existir uma extensa pesquisa longitudinal sobre a inteligência, parece ser necessário um olhar mais integrador com diferentes classes de preditores, sobretudo de natureza biológica, comportamental e motora, em simultâneo.

Não obstante a importância dos fatores biológicos na explicação das diferenças no crescimento físico, desempenho motor e cognitivo de crianças e jovens, é inegável a importância dos fatores contextuais. No período pré-escolar e escolar, as crianças passam a maior parte do seu dia nas instituições de ensino, razão pela qual as escolas são, provavelmente, consideradas as instituições mais organizadas e estruturadas para o desenvolvimento infantil (Morgan et al., 2013). Por exemplo, Chaves et al. (2015) procuraram identificar caraterísticas das crianças e das escolas na explicação de diferenças inter-individuais na CMG. As variáveis escolares explicaram 10% da variação total. Apesar de não conseguirmos localizar estudos longitudinais com informação hierarquicamente organizada e com dados do contexto escolar focando nas mudanças ocorridas na CMG, Bai et al. (2017) sugerem que as mudanças nos níveis de ApTF de crianças diferem de acordo com a dimensão da escola e caraterísticas socioeconómicas.

Uma das perspetivas de pesquisa mais corrente em Desenvolvimento Motor foca o estudo da mudança de habilidades e aptidões à flecha do tempo, i.e., a idade cronológica. Contudo, nem sempre é fácil encontrar pesquisa que tente responder a um conjunto interligado de planos - concetual, metodológico e analítico. Collins (2006) sugere, com bastante persuasão, a urgência de conectar três etapas sequenciais e interligadas na pesquisa da “coisa desenvolvimentista”: (1) o recurso a um modelo teórico bem estruturado para compreender a magnitude e sinal da mudança; (2) a utilização de um delineamento temporal que favoreça uma visão clara e minuciosa dos processos de estudo; e (3) o recurso a modelos estatísticos flexíveis e eficazes para tratar adequadamente a informação disponível. Ademais, Collins (2006) refere, explicitamente, o recurso a um modelo estatístico para tratar a informação longitudinal – o modelo hierárquico ou multinível desenvolvido por diferentes autores e explicitamente disponível em *software* de fácil entrada como o *Hierarquical Linear Modeling* (HLM) (Bryk & Raudenbush, 1987) ou o SuperMix (Hedeker, Gibbons, du Toit, & Cheng, 2008). A sua flexibilidade permite a análise e interpretação da dinâmica relacional da mudança intra-individual e das diferenças inter-individuais, bem como a inclusão de preditores situados em diferentes planos da hierarquia organizacional da informação.

Baseados numa abordagem empírica com delineamento longitudinal-misto, centrado na modelação multinível com ligações à teoria bio-ecológica de Bronfenbrenner, foram realizados diferentes programas de pesquisa historicamente situados nas Regiões Autónomas da Madeira (Freitas et al., 2002) e dos Açores (Maia & Lopes, 2007), no Cariri Cearense no Brasil (Silva, 2010), Muzambinho no Brasil (Basso et al., 2009) e no Porto (de Souza, 2014). Esta tendência consolidou conhecimentos e estratégias que permitiram a realização de um novo desafio em Vouzela, centro do país, designado de *Growth, Motor Development and Cognition Study* (*GMDC-Vouzela Study*) (Reyes et al., 2018). Este desafio nasceu no ano letivo de 2013/2014 a partir de um programa de pesquisa designado de Vouzela Ativo, fase 3, cujo propósito está implícito no próprio título e mais adiante detalhado (Capítulo II da presente tese). Partindo de um delineamento longitudinal-misto, com dois anos de sobreposição, procurou-se desenvolver um olhar abrangente e multifacetado sobre o nexo relacional que se estabelece entre crescimento físico, desempenho motor e desempenho cognitivo. O esforço interpretativo do *GMDC-Vouzela Study* está direcionado para a descrição, interpretação e predição da dinâmica da mudança de um vasto conjunto de variáveis preditivas das categorias centrais da pesquisa – crescimento, desempenho motor e desempenho cognitivo. Daqui o recurso a informação sobre o período gestacional e suas caraterísticas, bem como, os primeiros anos de vida, a preferência manual, o estatuto socioeconómico da criança e da família, a prática de AF e o contexto escolar (Figura 4) durante três anos consecutivos.

Essencialmente, o conteúdo desta tese expressa as ideias, marcos, limitações e perspetivas futuras associadas ao programa de pesquisa realizado em Vouzela, associando crescimento físico, desempenho motor e desempenho cognitivo de crianças dos 4 aos 11 anos de idade. Os propósitos específicos são os seguintes:

- Apresentar as principais ideias, o desenho geral e domínios metodológicos do *GMDC-Vouzela Study*, bem como, relatar sucintamente os resultados do primeiro ano de pesquisa (*baseline*), comparando meninos e meninas, para uma variedade de marcadores, sobre crescimento, desenvolvimento motor e cognitivo e caraterísticas de estilo de vida.

- Descrever e interpretar o crescimento físico de crianças Vouzelenses, dos 4 aos 11 anos de idade.

- Descrever e interpretar as mudanças do desempenho da CMG de crianças em função do dinamismo relacional de caraterísticas individuais, através de um conjunto de preditores (fixos e dinâmicos).

- Descrever e interpretar as mudanças do desempenho da ApTF de crianças em função do dinamismo relacional de caraterísticas individuais, através de um conjunto de preditores (fixos e dinâmicos).

- Descrever e interpretar as mudanças do desempenho da inteligência de crianças em função do dinamismo relacional de caraterísticas individuais, através de um conjunto de preditores (fixos e dinâmicos).

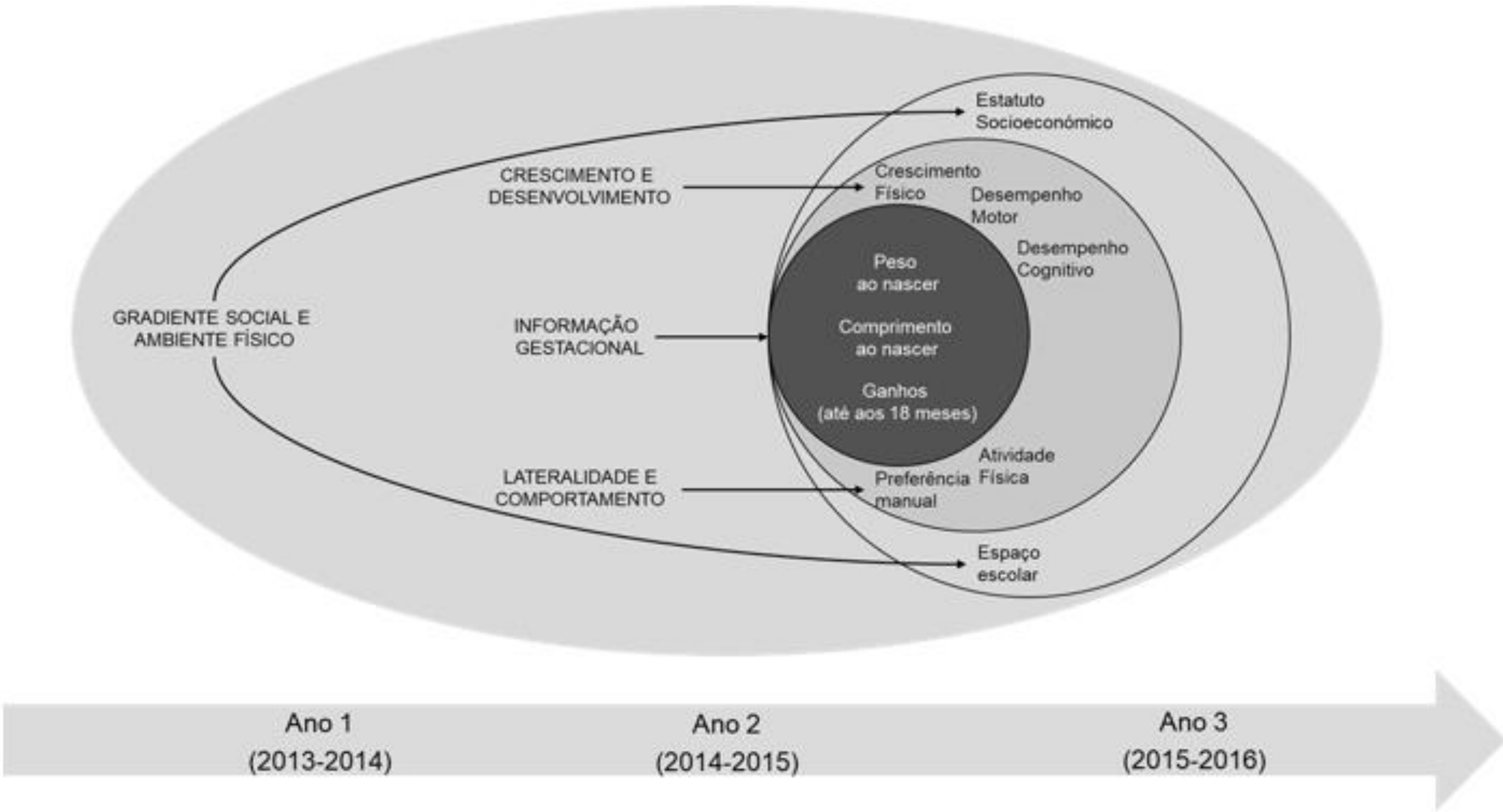

Figura 4. Modelo sequencial das diferentes variáveis estudadas nas três janelas do tempo do *GMDC-Vouzela Study.*

ESTRUTURA DA TESE

A presente tese foi organizada de acordo com o designado "modelo Escandinavo". Em função dos objetivos delineados, seguem-se os capítulos em forma de artigos, cuja disposição está na Tabela 1. Os artigos da tese encontram-se escritos em língua inglesa e foram submetidos e/ou publicados em periódicos de referência, encontrando-se formatados de acordo com as respetivas normas de publicação.

O capítulo I apresenta a introdução geral, os principais pilares da pesquisa e seus objetivos, bem como a estrutura da tese. O capítulo II refere-se à metodologia geral, apresentando um brevíssimo sumário do projeto Vouzela Ativo. É constituído de um artigo de cariz metodológico descrevendo, de modo aprofundado, os instrumentos e protocolos de avaliação. O capítulo III contém os quatro artigos analíticos. As conclusões gerais são apresentadas no capítulo IV, bem como as limitações da presente tese e as questões direcionadas a pesquisas futuras. No final de cada capítulo está referida a bibliografia de acordo com as normas da revista a que cada artigo foi submetido ou que esteja em processo de submissão. Os capítulos gerais da tese [I, II (com exceção do artigo I) e IV] apresentam as referências bibliográficas em concordância com as normas da Faculdade de Desporto da Universidade do Porto (FADE-UP).

Tabela 1 - Estrutura da tese

Capítulo I	Apresenta a introdução geral, os aspetos relativos à relevância do estudo, os principais propósitos e a estrutura da tese.
Capítulo II	Descreve os aspetos metodológicos relativos à amostra estudada, instrumentos e protocolos utilizados. **Artigo I** **A mixed-longitudinal study of children´s growth, motor development and cognition. Design, methods and baseline results on sex-diferences.** Objetivos: apresentar as principais ideias e metodologias do projeto *Growth, Motor Development and Cognition Study (GMDC-Vouzela Study)*, bem como os resultados do primeiro ano do estudo. *Artigo publicado: Annals of Human Biology (2018), doi: 10.1080/03014460.2018.1511828.*

Autores: Ana Reyes, Raquel Chaves, Adam D. G. Baxter-Jones, Olga Vasconcelos, Go Tani, José Maia.

Capítulo III

Artigo II
Modelling the dynamics of children´s growth. The Vouzela study on growth, motor development and cognition.

Objetivos: (1) modelar o crescimento das crianças na altura, peso e índice de massa corporal; (2) investigar diferenças entre sexos; (3) investigar os efeitos do estatuto socioeconómico, do peso e comprimento à nascença, e ganhos de peso e comprimento até os 18 meses nestes marcadores de crescimento.

Artigo para submissão: Revista Portuguesa de Ciências do Desporto.

Autores: Ana Reyes, Raquel Chaves, Adam D. G. Baxter-Jones, Olga Vasconcelos, Go Tani, José Maia.

Artigo III
Modelling the dynamics of children´s gross motor coordination.

Objetivos: (1) modelar o desenvolvimento da coordenação motora grossa de crianças; (2) investigar diferenças entre sexos; (3) identificar os efeitos de variáveis fixas e dinâmicas no desenvolvimento da coordenação.

Artigo publicado: Journal of Sports Sciences (2019), doi: 10.1080/02640414.2019.1626570.

Autores: Ana Reyes, Raquel Chaves, Adam D. G. Baxter-Jones, Olga Vasconcelos, Lisa M. Barnett, Go Tani, Donald Hedeker, José Maia.

Artigo IV
Examination of children´s physical fitness trajectories using a comprehensive multilevel modelling approach.

Objetivos: (1) modelar o desenvolvimento da aptidão física de crianças; (2) investigar diferenças entre sexos; (3) investigar os efeitos dos preditores fixos e dinâmicos nas mudanças na aptidão física.

Artigo submetido: Child Care, Health and Development.

Autores: Ana Reyes, Raquel Chaves, Adam D. G. Baxter-Jones, Olga Vasconcelos, Go Tani, David Stodden, Donald Hedeker, José Maia.

Artigo V
Biological, behavioural, and socioeconomic correlates of children changes in performance IQ.

Objetivos: (1) modelar o desempenho da inteligência das crianças; (2) investigar diferenças entre sexos; (3) identificar os efeitos das variáveis fixas e dinâmicas nas mudanças da inteligência.

Artigo para submissão: Jornal de Pediatria.

	Autores: Ana Reyes, Raquel Chaves, Adam D. G. Baxter-Jones, Olga Vasconcelos, Go Tani, José Maia.
Capítulo IV	Apresenta as conclusões finais, limitações da tese, bem como desafios futuros.

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CAPÍTULO II

METODOLOGIA GERAL

METODOLOGIA GERAL

Breve caraterização do Concelho de Vouzela

O Concelho de Vouzela encontra-se situado no Distrito de Viseu, na Região Centro de Portugal, na província de Beira-Alta e sub-região Dão-Lafões, cerca de 27 km de Viseu e a cerca de 66 km de Aveiro. É constituído por 9 freguesias (Alcofra, Campia, Fornelo do Monte, Queirã, São Miguel do Mato, União de Freguesias de Cambra e Carvalhal de Vermilhas, União de Freguesias de Fataunços e Figueiredo das Donas, União de Freguesias de Vouzela e Paços de Vilharigues, Ventosa), ocupa uma área de 193.7 km^2 e estabelece fronteira com Viseu, Tondela, São Pedro do Sul e Oliveira de Frades, outros concelhos do Distrito (Câmara Municipal de Vouzela, 2011) (ver Figura 1.).

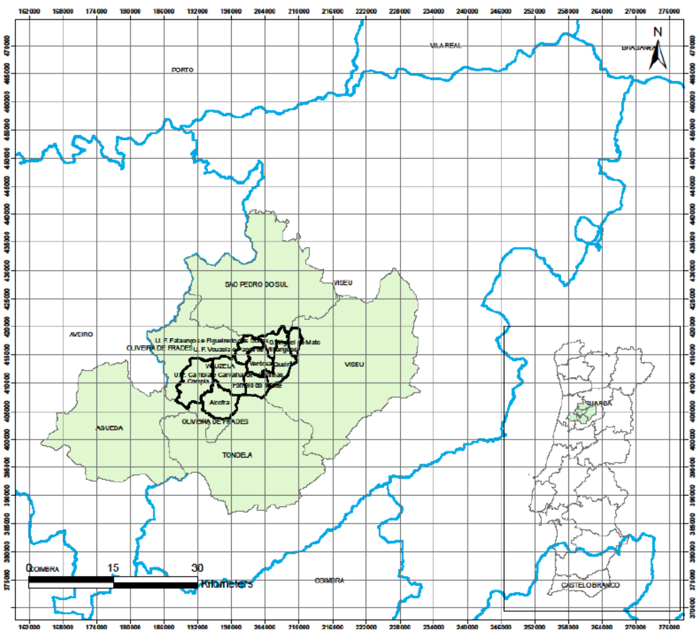

Figura 1 - Enquadramento geográfico do Concelho de Vouzela

Fonte: PMDFCI (2015)

Apesar da proximidade de grandes polos urbanos e inserido num processo de transição económica, o que o distingue de tantas outras regiões com origens históricas e caraterísticas culturais similares, é a preservação da sua ruralidade e da interioridade. Todo o seu território situa-se numa zona montanhosa que constitui a Serra do Caramulo e a Serra da Arada e é marcado por uma grande variação de altitude, entre 125 m a 1040 m. É forte também a presença de água ao longo do território do Concelho, firmado na bacia do Rio Vouga e por outras linhas superficiais como os Rios Zela, Troço, Alcofra, Alfusqueiro e Couto e a Ribeira de Ribamá (Gabinete Ténico Florestal, 2015a, 2015b).

Até o final do século XX, o Concelho de Vouzela tinha como atividade principal económica o setor primário. Entretanto, sua estrutura socioeconómica sofreu algumas modificações, com uma diminuição das atividades agrícolas e um aumento no setor secundário. Atualmente grande parte da população ativa trabalha na indústria e no comércio, muito embora a tradição agrícola ainda seja forte. Essa transição económica pode estar relacionada, de acordo com o Departamento de Planeamento da Câmara Municipal de Vouzela, com as políticas agrícolas nacionais e europeias, com a imigração da população para outros locais com maior oferta de emprego e melhores salários (Câmara Municipal de Vouzela, 2011).

Atualmente, e em termos demográficos, a população total do Concelho de Vouzela é de 10.350 habitantes de acordo com o último censo populacional (Instituto Nacional de Estatística, 2017), com maiores densidades populacionais na União de Freguesias de Vouzela e Paços de Vilharigues e União de Freguesias em Fataunços e Figueiredo das Donas. Em comparação com os dados reportados pelo censo de 2011 (10.540 habitantes) houve um ligeiro decréscimo populacional, muito provavelmente explicado pela escassez de condições que garantam um padrão de qualidade de vida moderado ou elevado, i.e., oportunidades de emprego, infraestruturas, espaços públicos (Pereira, Marta, & Peixoto, 2011).

Em termos de saúde, os serviços estão concentrados no Centro de Saúde de Vouzela, localizado na sede do município e inserido no Agrupamento de Centros de Saúde (ACeS) do Dão-Lafões (ACeS Dão-Lafões, 2015). Os programas desenvolvidos na comunidade inserem-se no Plano Nacional de Saúde (PNS), direcionados para diferentes faixas etárias. O Hospital São Tenório, em Viseu (Centro Hospitalar Tondela-Viseu, EPE), é o hospital de referência utilizado pelo Centro de Saúde de Vouzela em casos que requerem uma maior urgência e atenção.

A rede escolar do Concelho de Vouzela encontra-se segmentada em dois agrupamentos, segundo o regime jurídico de administração, gestão e autonomia, nomeadamente por Vouzela e Campia, onde as escolas estão outorgadas de acordo com a localidade. Na altura da recolha da informação (2013 a 2016), o agrupamento de escolas de Vouzela era integrado pelas instituições de ensino de Fataunços, Figueiredo das Donas, Fornelo do Monte, São Miguel do Mato, Paços de Vilharigues, Queirã, Ventosa e Vouzela. O agrupamento de escolas de Campia incluía as instituições de ensino de Cambra, Campia, Outeiro e Viladra.

Atualmente, há uma grande preocupação da autarquia do Concelho de Vouzela em oferecer e administrar diversas oportunidades de práticas de atividades físico-desportivas para todos os vouzelenses. O gabinete de desporto tem a seu cargo o planeamento e dinamização de vários projetos que constituem uma imagem de marca do trabalho junto da população do Concelho e, até mesmo, dos turistas que visitam a região. Dentre muitos projetos fazem parte o "Desporto Escolar", "As crianças marcam a diferença", "Vouzela em BTT" e o "Vouzela Ativo".

Caraterização da população de estudo e do projeto Vouzela Ativo

A presente tese é parte da terceira fase do projeto Vouzela Ativo, realizado no respetivo Concelho, a partir da parceria estabelecida entre a FADE-UP, especificamente do Laboratório de Cineantropometria e Estatística Aplicada, o Agrupamento de Escolas de Vouzela, e a Câmara Municipal de Vouzela.

A primeira fase do projeto foi implementada no ano letivo de 2006/2007, em que a preocupação inicial era mapear a população infantojuvenil entre os 7 e os 18 anos de idade, no que se refere ao seu crescimento físico (altura, peso e IMC) e níveis de competência físico-motoras (CMG, AF e ApTF), analisar as relações que se estabelecem entre elas, e estudar a saúde das famílias vouzelenses (fatores de risco metabólico, níveis de AF e composição corporal).

O primeiro relatório detalhado desta fase saiu sob a forma de um livro intitulado "Vouzela Ativo - um olhar sobre o crescimento, o desenvolvimento e a saúde das crianças, jovens e famílias do Concelho de Vouzela" (Maia, Silva, & Seabra, 2009). A segunda fase do projeto teve início em 2009/2010 com a renovação da parceria entre as instituições envolvidas e com intenções ainda mais vastas, avaliando um conjunto maior das caraterísticas das crianças e dos jovens vouzelenses, bem como o contexto familiar, escolar e desportivo. Um novo livro foi editado (Chaves et al., 2012) com o intuito não só apresentar os dados dessa segunda fase, mas também de realizar um contraste com os dados da primeira fase.

Finalmente, a terceira fase do projeto realizada nos anos letivos de 2013/2014 a 2015/2016 teve como objetivo descrever e interpretar, ao longo de três anos consecutivos, a dinâmica relacional entre crescimento físico, desempenho motor e cognitivo de crianças do pré-escolar e do 1º Ciclo do EB, bem como os múltiplos fatores que condicionam o seu desenvolvimento e que se situam ao nível das crianças, da escola, dos professores, da família e dos contextos ambientais. Durante os dois primeiros anos do Vouzela Ativo tiveram lugar dois seminários internacionais para "prestar contas" à população do Concelho de tudo quanto foi feito. A Figura 2 contém as ilustrações da divulgação dos seminários.

Figura 2 - Imagens dos dois seminários internacionais realizados em 2014 e em 2015

Em 2018, com o desfecho deste ciclo de quase dez anos com a população Vouzelense e a FADE-UP, assim como nas fases anteriores, foi editado um novo livro (Maia, Reyes, Tani, Vasconcelos, & Chaves, 2018). A Figura 3 contém as imagens dos livros publicados nas três fases do projeto Vouzela Ativo.

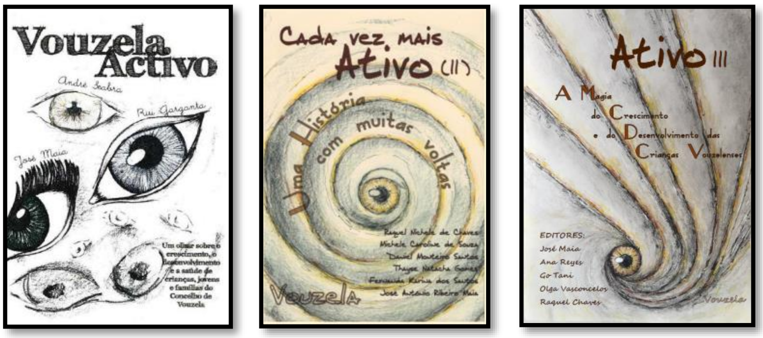

Figura 3 - Imagens dos livros publicados nas três fases do Projeto Vouzela Ativo

Com o intuito de divulgar a terceira fase do projeto Vouzela Ativo tanto nacionalmente quanto internacionalmente, e colocar o projeto designado *GMDC-Vouzela Study* no centro de pesquisas científicas, foi escrito um texto metodológico em língua inglesa abordando questões metodológicas (amostra, instrumentos e procedimentos), bem como apresentados resultados no *baseline*, e que se apresenta adiante.

Controlo da qualidade da informação

O controlo da qualidade de informação foi realizado em várias etapas. Em primeiro lugar, a equipa de avaliadores foi treinada por investigadores experientes do Laboratório de Cineantropometria e Estatística Aplicada da FADE-UP. Em segundo lugar realizou-se um estudo piloto, antes de começar o projeto Vouzela Ativo III, para se ter uma noção mais precisa dos problemas que poderiam surgir durante o processo de recolha da informação aos mais variados níveis. Em terceiro lugar, em cada ano de recolha, foi re-testada uma amostra aleatória de ~60 crianças (*in-field reliabillity*). Em quarto lugar foram calculadas as estatísticas habituais: o erro técnico de medida (ETM) e a correlação intraclasse (e respetivos intervalos de confiança (IC) a 95%).

Tabela 1. Erro técnico de medida e correlação intraclasse para cada ano de avaliação.

	Ano 1	Ano 2	Ano 3
Antropometria		**ETM**	
Altura (cm)	0.20	0.13	0.14
Altura sentado (cm)	0.19	0.13	0.11
Peso (kg)	0.09	0.08	0.09
Circunferência da cintura(cm)	0.23	0.17	0.16
Mass gorda (%)	0.45	0.47	0.52
Massa gorda (kg)	0.21	0.15	0.25
Massa isenta de gordura (%)	0.19	0.17	0.23
Coordenção motora grossa		**R (95%IC)**	
Equilíbrio à retaguarda	0.91 (0.86-0.95)	0.93 (0.87-0.96)	0.87 (0.78-0.92)
Saltos monopedais	0.82 (0.71-0.90)	0.94 (0.89-0.97)	0.94 (0.90-0.97)
Saltos laterais	0.88 (0.82-0.93)	0.96 (0.93-0.98)	0.89 (0.82-0.93)
Transposição lateral	0.78 (0.71-0.89)	0.85 (0.84-0.91)	0.83 (0.73-0.90)
Aptidão Física			
1-milha corrida/caminhada (min)	0.82 (0.66-0.90)	0.91 (0.85-0.95)	0.91 (0.85-0.94)
50 jardas (s)	0.78 (0.63-0.87)	0.71 (0.62-0.83)	0.88 (0.82-0.93)
Salto horizontal (cm)	0.94 (0.91-0.96)	0.96 (0.93-0.97)	0.93 (0.89-0.96)
Preensão manual (kg)	0.97 (0.95-0.98)	0.96 (0.94-0.98)	0.97 (0.96-0.98)
Corrida vai-vem (s)	0.88 (0.80-0.93)	0.96 (0.93-0.98)	0.93 (0.87-0.96)

Análise estatística

A análise exploratória, descritiva e inferencial dos dados, bem como procedimentos estatísticos multivariados foram realizados nos programas estatísticos SPSS 24.0 e WinPepi. A modelação multinível foi efetuada nos *softwares* SuperMix v.1 e STATA 15.0.

Questões éticas

A fase III do Vouzela Ativo foi aprovada pelo Comitê de Ética em Pesquisa da Faculdade de Desporto da Universidade do Porto (CEFADE 01.2016). O Termo de Consentimento Livre e Esclarecido foi assinado pelos pais e/ou encarregados de educação das crianças Vouzelenses.

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ARTIGO METODOLÓGICO

Artigo I

A mixed-longitudinal study of children's growth, motor development and cognition. Design, methods and baseline results on sex-differences

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ABSTRACT

Background: There is a renewed interest in longitudinal studies, which link children's growth, motor and cognition development. This is important for both educational outcomes and identification of children who are at risk.

Aim: To identify cross-sectional sex-differences.

Subjects and methods: In total, 1166 Portuguese children, aged 4–11 years, were recruited into the Growth, Motor Development and Cognition Study (GMDC-Vouzela Study). Measures included anthropometry, gestational development, motor coordination, cognitive performance, laterality, physical fitness, metabolic syndrome risk, lifestyle characteristics and environmental exposures. Analysis of covariance was used to compare outcomes between boys and girls, adjusting for chronological age.

Results: Most variables did not show significant differences between the sexes ($p>0.05$). However, girls had more body fat mass than boys ($p<0.05$) and boys were significantly heavier at birth ($p<0.05$); furthermore, boys outperformed girls in a hopping high coordination test ($p<0.001$) and were more physically fit ($p<0.05$).

Conclusions: Baseline results from the GMDC-Vouzela Study indicate the dynamic relationships between children´s biological and environmental characteristics. They also highlight lifestyle traits that will most likely effect subsequent growth, motor and cognitive development.

Keywords: Children; growth; development; mixed-longitudinal study; methods

Introduction

Children's physical growth, motor and cognition development are strongly inter-related processes that exhibit, at any given point in time, the interplay of genes and the environment (Malina et al. 2004). During childhood and adolescence steady gains in height and weight are highly visible in both boys and girls and show marked sex-differences, particularly in adolescence (Tanner 1981). During growth, fundamental movement skills are acquired and refined, and are highly influenced by biological maturation and the learning process. As children age, such skills start transitioning into more specialized movement patterns related to the challenges of sports in a more formal context (Haubenstricker and Seefeldt 1986). Additionally, cognitive skills, such as memory and language, show clear improvements as a child begins to think more concretely (Piaget 1969). It has also been reported that these patterns of motor and cognitive development are important for subsequent healthy living (Papalia et al. 2006; Lubans et al. 2010).

Changes, and stability, in motor or cognitive performance during growth show remarkable sex and inter-individual variability; these are governed by a plethora of factors (Branta et al. 1984; Fredricks and Eccles 2002). To better understand and unravel the independent effects of growth and motor performance, longitudinal study designs are required (Laursen et al. 2012). The ability of longitudinal studies to tweeze out the effects of growth from those of motor performance development provides child educators the ability to identify the needs and priorities required for children's first years of schooling

Although there is a renewed interest in being able to better describe and understand the links among different domains of children and adolescents' physical, motor and cognitive development (Donnelly et al. 2016), interpretation is limited by the use of cross-sectional designs (Chaddock, Erickson, et al. 2012; Lambourne et al. 2013). In general, positive relationships have been reported between domains suggesting, for example, that higher levels of physical activity (PA) and/or physical fitness (PF) are positively associated with higher cognitive performance, mainly in executive functions, memory, attention and academic achievement (Haapala 2013). However, to determine the cause-effect relationships longitudinal studies are required to fully address the dynamic complexities of such relationships (Chaddock, Hillman, et al. 2012; Wittberg et al. 2012).

Motor coordination is one of the fundamental aspects of motor development (Savelsbergh et al. 2003), and its links to cognitive development have been explored, mostly with fine motor coordination (Carlson et al. 2013; Pacheco et al. 2016). Yet, information concerning these relationships with gross motor coordination (GMC) and their putative sex-differences are still limited (Lopes et al. 2013; Fernandes et al. 2016). Moreover, available longitudinal data concerning children and adolescents´ GMC is relatively scarce (Willimczik 1980; Deus et al. 2010; D'Hondt et al. 2013; Antunes et al. 2015). Additionally, there is a paucity of information identifying and linking the dynamics of GMC changes to time-varying effects of physical activity, weight status, and physical fitness during the kindergarten and primary school years (Henrique et al. 2017) and the sex-differences that likely occur. This lack of information is concerning as these ages represent an important developmental time window for the acquisition and refinement of fundamental movement skills and the improvement of motor coordination associated with daily tasks (Roberton and Halverson 1984; Clark and Humphrey 1985).

Children evolve under a diversity of contextual/environmental factors, such as the family homes, daily leisure activities with their peers as well as in their schools. For example, Glick et al. (2011) investigated the relationship between household characteristics and school factors with cognitive skills in children (8-10 yrs) and adolescents (14-16 yrs), and found that mothers' schooling had a relevant role in children’s learning; in addition, they suggested that teachers experience, as well as schools infrastructures, were also important covariates. Chaves et al. (2015), using a multilevel approach, reported that 10% of the total variance in GMC in children was explained by the school context. Based on Bronfenbrenner (1977, 1979) ecological approach, we designed a three years mixed-longitudinal study (GMDC-Vouzela Study) aiming to address the dynamics of the relationships between child characteristics and lifestyle indicators from 4 to 11 years of age. The aims of this paper are: (1) to present the overall design and methodology of the GMDC-Vouzela Study, and (2) report baseline results between boys and girls for a variety of markers, but not all, concerning growth, motor and cognitive development, and lifestyle characteristics.

Material and Methods

Design and Sample

The GMDC-Vouzela Study recruited children living in the middle of Portugal, the Vouzela region which is considered to be a medium urban area. This region covers an area of 193.7 km^2 and has ~10.500 inhabitants scattered around twelve villages. The agricultural landscape has systematically influenced the economy and development of the region (City Hall of Vouzela 2011). Vouzela has two main schools, clustering nineteen kindergartens and primary schools; all children attending these schools were invited to participate. A convenient cluster sampling strategy was adopted (schools and children), and the response rate was ~90%; 10% of children did not receive permission from parents or legal guardians or had physical handicaps that limited their ability to perform the tests. Recruited children were assigned into one of six overlapping age cohorts (Table 1). Observations´ numbers per cohort ranged from 171 to 212 (~50% boys).

Initial measurements, with the exception of reading comprehension, were taken in March 2014 through to July 2014 and annually thereafter until July 2016. Children from each cohort were measured in the same month, within a window of 5-10 days. Similarly, the reading comprehension assessments were taken in September 2014 through October 2014 and annually thereafter until October 2016 within the same window of opportunity. This was performed to help prevent

Table 1 - Cohorts, overlapping ages and total sample size per cohort, age, and sex (F=Female; M=Male)

Cohorts	**Ages**								**Total**
Cohort 1	4 (43F, 45M)	5 (30F, 32M)	6 (18F, 21M)						189 (91F, 98M)
Cohort 2		5 (32F, 46M)	6 (19F, 32M)	7 (18F, 24M)					171 (69F, 102M)
Cohort 3			6 (45F, 36M)	7 (36F, 29M)	8 (32F, 23M)				201 (113F, 88M)
Cohort 4				7 (36F, 35M)	8 (32F, 32M)	9 (27F, 23M)			185 (95F, 90M)
Cohort 5					8 (35F, 39M)	9 (32F, 39M)	10 (28F, 35M)		208 (95F, 113M)
Cohort 6						9 (45F, 33M)	10 (37F, 29M)	11 (38F, 30M)	212 (120F, 92M)
Total	88 (43F, 45M)	140 (62F, 78M)	171 (82F, 89M)	178 (90F, 88M)	193 (99F, 94M)	199 (104F, 95M)	129 (65F, 64M)	68 (38F, 30M)	1166 (583F, 583M)

the possibility of seasonal effects. Informed consent was provided by parents/legal guardians. The School authorities, the Vouzela Health Center, and the Ethics Committee of the Faculty of Sport, University of Porto, approved the project.

Measurements

Collected data covered basic anthropometry, gestational information, motor and cognitive development, laterality, physical activity, physical fitness, socioeconomic status, nutritional behavior, metabolic risk factors, school environment, neighborhood and family environment, as well as infrastructures and sports´ equipment. Table 2 summarizes the data collected during the three years of the study.

Anthropometry and body composition

Anthropometric measurements, including height, weight, sitting height and waist circumference, were collected following the protocols of the International Society for the Advancement of Kinanthropometry (Ross and Marfell-Jones 1991). Using a portable stadiometer (Holtain, UK), height and sitting height were measured in children, without shoes, holding their heads in the Frankfurt plane, with a precision of 0.1 cm. Waist circumference (WC) was anatomically identified as the smallest circumference between the lowest rib and the superior border of the iliac crest; measured using a metal anthropometric tape (Sanny, American Medical of Brazil, Brazil) with a precision of 0.1 cm. Body weight (kg) was measured with children in light clothing and with a 0.1 kg precision using a portable bioelectrical impedance scale (TANITA BC-418 MA Segmental Body Composition Analyzer; Tanita, Corporation, Japan). The scale also allowed the estimation of body fat mass (BFM) and fat-free mass. Body mass index (BMI) was computed according to the standard formula BMI=[body mass (kg)/height (m)^2], and the International Obesity Task Force (Cole et. al.2000) cut-points were used to classify children as normal weight, overweight or obese.

Gestational Information

Gestational information was obtained by questionnaire, as well as from children's health booklets. The following information was collected: gestational age, number of consultations during pregnancy, length at birth, cephalic perimeter, pregnancy and birth complications, use of medicines and drugs (licit or illicit), type of gestation and birth, children birth weight and length. Birth weight was classified according to the WHO (1992) as follows: low weight (≤2500g), normal weight (>2500g) and overweight (>4000g). Further, data were also collected concerning children´s growth (height and weight) during their first two years of life by the nurses of the Vouzela Health Center during scheduled visits, usually every three to six-months.

Motor Co-ordination

Gross motor coordination (GMC) was assessed using the *KöperkoordinationsTest für Kinder test* battery (KTK) developed by Kiphard and Schilling (1974) for children and adolescents from 5 to 14 years of age. The battery comprises four tests: (1) walking backwards on a balance beam (WB); children walk backwards 3 times on each of 3 different balance beams, and the number of successful steps recorded; (2) hopping for height on one foot (HH); children hop on a pile of pillows which increases in number with each success completion (3 attempts are allowed at each height). A maximum of 39 points (ground level plus 12 pillows) can be achieved for each foot giving a maximum possible score of 78 points; (3) jumping sideways (JS); children jumps laterally as fast as possible over a small wooden slat for 15 s. The task is repeated twice and the number of jumps over the two trials summed. (4) moving sideways on boxes (MS); children stand with both feet on a platform and place both hands on an adjacent platform. They then place the second platform alongside the first and step on it. This movement is repeated as fast as possible during a 20s trial (2 trials). The total number of relocations (2 points) per trial was recorded and summed. The unweighted sum of the scores of the four KTK tests was used as a measure of total GMC (TGMC) following procedures outlined by Schilling (2015).

Upper limbs motor coordination, namely fine motor dexterity (drawing trail) and aiming and catching (catching bean bag; two-hand catch; one-hand catch; throwing bean bag into box; throwing bean bag onto a mat; throwing bean bag at a wall target) were assessed with the Movement Assessment Battery for Children-2 (MABC-2) as described by Henderson and Sugden (2007). These tests are recommended for children and adolescents aged 3 to 16 years, in three age groups: (i) children 3 to 6 years old; (ii) children 7 to 10 years old; and (iii) children 11 to 16 years old. Results related to these tasks are converted into scores as recommended by Henderson et al. (2007) and later equated by using Item Response Theory.

Cognitive Performance

Cognitive performance was assessed in three domains: (i) reading skills; (ii) intelligence; and, (iii) academic performance. To assess reading comprehension, a reading performance test battery was used which was composed of three different tests: (1) narrative and informative oral comprehension; (2) narrative and informative reading comprehension; and (3) reading words. This battery was developed and validated for Portuguese children by Ribeiro and Viana (2014). To assess intelligence, the Wechsler Intelligence Scale for Children - 3rd edition (WISC-III), cross-culturally validated to the Portuguese population by Simões et al. (2003) was used. Given shortage of personnel (only registered Psychologists have the capability to do the assessments), time and budget constraints only the non-verbal sub-scale comprising seven sub-tests (complete figures, arrangement of figures, code, cubes, arming objects, looking for symbols and labyrinths) was used; because of this, only children from cohort 3 and above were assessed. Thirdly, academic performance in the Portuguese language, Mathematics and Social Sciences was obtained from teachers´ assessments. These assessments are based on a common pedagogical strategy, and children are rated on an ordinal scale: (1) insufficient; (2) does not satisfy; (3) satisfies; (4) good; (5) very good.

Laterality

Laterality was assessed in three distinct domains: manual preference (MP), pedal preference (PP) and ocular preference (OP). Manual preference was assessed by The Dutch Handedness questionnaire shorter version (Van Strien 2003). This questionnaire consisted of ten items related to simple activities of daily living (i.e. pick up a pencil, hold the toothbrush) and was self-reported. In young children it is advised that they carry out all activities using the objects mentioned in their respective questions (Scharoun and Bryden 2014). For the present study it was decided to use the MP as a dichotomous variable as indicated by Van Strien (2003) to compare two distinct groups. For each task performed the evaluator indicted whether the right hand (RH) was used; assigning the value +1; or the left hand (LH); assigning the value -1. If there was no preference for using any of the items; assigning the value 0. The left hand preference (LHP), with scores between -10 and +3, and right hand preference (RHP) with scores between +4 and +10. The Card-reaching Test (Carlier et al. 2006) was used as a complement of the above mentioned questionnaire to classify the children´s MP but also to classify the direction and consistency of the their MP. Pedal and ocular preference were assessed using the Lateral Preference Inventory (Porac and Coren 1981) enabling a dichotomous classification.

Physical Fitness

Physical fitness (PF) was assessed using two tests batteries: (i) Fitnessgram (1994); and; (ii) the AAHPERD Youth Fitness Test (American Alliance for Health 1980). Tests include: (1) 1-mile run/walk tests (aerobic fitness); children ran/walked 1-mile (1609m) and their time was recorded. (2) 50 yard dash test (speed); children ran 50 yards and their time was recorded; (3) standing long jumps test (explosive leg power); children jumped as far as possible from a standing position; (4) grip strength test (static strength); children griped a dynamometer (Takei Physical Fitness Test GRIP-D, Japan) with maximum force for five to ten seconds; and (5) shuttle-run test (agility); children ran as fast as possible from a starting line to a line nine meters away, where two small wooden blocks were placed, picked-up one of the blocks and returned to the starting line, placed the block on the line, and then repeated the task and the time to completion was recorded.

Metabolic risk factors

Children, from the primary school, initially identified as overweight or obese using BMI cut-points were further examined regarding using metabolic risk factors: (1) waist circumference; (2) systolic (SBP) and diastolic (DBP) blood pressure; (3) blood samples assessed for high-density lipoprotein-cholesterol (HDL-C); (4) fasting glucose (GLU); and, (5) triglycerides (TRI). Children were asked to be on a fasting condition of 10-12 hours. Resting SBP and DBP were measured using a digital Omron sphygmomanometer (Omron M6 hem-7001-E) after children had been at rest for at least 10 minutes (National High Blood Pressure Education Program Working Group on High Blood Preesure in Children and Adolescents 2004). The blood parameters (HDL-C, GLU and TRI) were collected by finger-stick blood sample and analyzed with a Cholestech LDX point of care analyzer (Cholestech Corporation, Hayward, CA, USA) (LDX, 2003) according to manufacturer´s indications. All these additional assessments, with the exception of WC, were performed by the nurses of the Vouzela Health Center of the 81 identified children, 70 had parental/guardians authorization to proceed with this assessment.

Lifestyle characteristics

Physical Activity

Physical activity (PA) was assessed using a tri-axial accelerometer (Actigraph, GT3X+, Pensacola, USA). Children were encouraged to wear the accelerometer for 7 days (5 week-days and 2 week-end days), and to remove the device during water activities (i.e, swimming, showering) and during sleep. The accelerometer was placed on the iliac crest and held in place by an elastic belt with adjustable clip. The minimal amount of accelerometer data that was considered acceptable was 4 days with at least 10 hours of daily wear time, including at least one week-end day. PA variables were derived using cut-points developed by Evenson et al. (2008). Meeting the recommendation of 60 min·day^{-1} of moderate-to-vigorous physical activity (MVPA) as proposed by the World Health Organization (WHO) was adopted to identify physically active children, considering the average of the valid days.

Nutritional Behavior

Children's nutrition was assessed using the Children's Eating Behavior Questionnaire (CEBQ), validated for the Portuguese populations (Viana and Sinde 2003). The questionnaire was completed by the mother and comprises seven dimensions; (1) response to food; (2) pleasure in eating; (3) response to satiety; (4) slow ingestion; (5) selectivity, about emotional ingestion; (6) emotional under-eating; and (7) desire to drink; all answers are on a 5-point Likert scale (never, rarely, sometimes, oftentimes, always).

Sleep habits

Parents answered a questionnaire regarding their children sleeping habits, namely how many hours they usually slept on weekdays and weekends. Then, sleep time was estimated from average weekly time (expressed in hours) and children were categorized into two groups (<10h·day^{-1}; ≥10h·day^{-1}) based on the National Sleep Foundation recommendations (2013).

Screen Time

Children´s screen time information was obtained via a questionnaire answered by parents about time (hours) spent during the weekdays, watching TV and using the computer or playing non-active video games; and during the weekend for the same measures. Five responses were categorized: (1) <30min.; (2) 30min-1h; (3) 1h-1h30min; (4) 1h30min-2h; (5) > 2h. A sum of all questions (weekdays and weekend) was made and then categorized according to the recommendations for children (<120 min·day^{-1}; ≥ 120 min·day^{-1}) (Barlow 2007).

Demographic and environment

Socioeconomic status

Socioeconomic status (SES) was determined by the Portuguese school social support system, which is the same across the country and is based on the index budget reference from the Ministry of Education directives. Families are divided into three levels according to their annual income as follows: level A (up-to 2,934.00 €·year^{-1}), and children get support for books and feeding (lunch at school); level B (from 2,935.00 to 5,896.00 €·year^{-1}), with half of level-A reimbursement value; level C (≥5,897.00 €·year^{-1}), and children receive no school support. Parent´s occupations were also assessed and classified according to the Portuguese National Classification of Occupations from the Portuguese National Statistics Institute (INE 2010) and categorized into nine groups: (0) armed forces; (1) central administration/politicians and executive directors; (2) specialists of intellectual and scientific activities; (3) technicians and intermediate level jobs; (4) back-office jobs; (5) security, seller and individual services; (6) farmer and qualified workers of farm, fish and forest; (7) industry and building jobs; (8)machine and equipment operators and (9) non-qualified jobs.

School environment

The description and inventory of different aspects related to the school context was obtained via a questionnaire developed by the authors in cooperation with the Vouzela city-hall Education Department. It maps the following domains: (1) school characterization (location; size and setting – rural, semi-urban and urban as determined by the Portuguese National Statistics Institute; (2) policies and practices to stimulate physical activity and nutrition; (3) physical structure of the school (playground, multi-sports roofed, facilities and equipment for physical education); (4) physical education (PE) classes; (5) human resources (number of teachers in each school, academic degree of them and teaching time).

Neighbourhood and family environment

A questionnaire about the neighbourhood and family environment characteristics was used to describe this relationship as well as family habits (demographics, ethnicity, family health and socioeconomic factors). This questionnaire was adapted from the original version used in the International Study of Childhood Obesity, Lifestyle and the Environment (ISCOLE) (Katzmarzyk et al. 2013).

Infrastructure and sports equipment

Based on data from the Vouzela City-Hall Sports Charter, all equipment aimed to do physical exercise was classified and spatially located by geographical reference systems (Clayton 1971), according to the following indicators: (1) complex Sports' facilities (including sports fields and courts, swimming pools and fitness area); (2) public parks (natural or semi-natural green areas used for recreational activities); (3) sports fields and courts; (4) playgrounds (external environment or covered with a specific design for the children's audience).

Data quality control

A series of procedures were used for data quality control: (1) the team was trained by experienced researchers of the Kinanthropometry Laboratory of the Sports Faculty, University of Porto, Portugal, following the same protocols; (2) a pilot study was conducted before the starting of the study to assess the quality of data collection procedures; (3) during each year of the data collection, a random sample of children was re-assessed (in-field reliability).

Statistical analysis

Exploratory and descriptive data analyses were conducted using SPSS 24.0 to identify input data errors as well as outliers and normality checks. An analysis of covariance (ANCOVA) for continuous data, adjusted for chronological age, was used for comparisons of baseline results between sexes. Chi-square tests (χ^2) were also used for categorical data. Further, partial eta squared (η_p^2)

and phi (ϕ) coefficient were used as measures of effect size. The significance level was set a 5%.

Results

Descriptive statistics (mean ± SD) for continuous data for anthropometry, gestational data, motor coordination, physical activity, physical fitness, cognitive performance and sleeping habits are shown in Table 3. Results from the ANCOVA analysis indicated that there were only a few significant differences between the sexes. Girls had more BMF (kg) mass than boys ($p=0.036$; $\eta_p^2=0.019$). Boys were significantly heavier at birth ($p=0.005$; $\eta_p^2=0.023$) and had a larger cephalic perimeter ($p=0.005$; $\eta_p^2=0.030$); further, they outperformed girls in the HH coordination test ($p<0.001$; $\eta_p^2=0.053$), were more physically fit (1-mile run/walk: $p<0.001$; $\eta_p^2=0.095$; 50-yard dash: $p=0.001$; $\eta_p^2=0.052$; standing long jump: $p<0.001$; $\eta_p^2=0.064$; handgrip: $p=0.009$; $\eta_p^2=0.020$; shuttle-run: $p=0.023$; $\eta_p^2=0.015$); and also more active ($p<0.001$; $\eta_p^2=0.188$).

Table 2 - Study domains, measurements, and participation of three years of the study.

Domains	Measurements	Participation
Anthropometry (physical growth and body composition)	- Anthropometry: height, sitting height, weight, waist circumference, BMI	All children
	- Body composition: BFM and fat-free mass	Starting at 7 yrs
Gestational Information	-Gestational age, birth weight, pregnancy questionnaire	All children*
Motor Coordination	- Gross motor coordination	Starting at 5 yrs
	- Fine motor dexterity - Aiming and catching	All children
Cognitive Performance	- Reading skills	Children from elementary school
	- Intelligence	Starting at 6 yrs**
	- Academic Performance	Children from elementary school
Laterality	-Hand preference -Pedal preference -Ocular preference	All children*
Physical Fitness	- Aerobic fitness - Speed	Children from elementary school
	- Explosive leg power - Static strength - Agility	All children
Metabolic risk factors	- Glucose - HDL-C - Triglycerides - Blood pressure	Overweight/obese children
Lifestyle characteristics	- Physical activity (accelerometer)	All children
	- Nutritional behavior (questionnaire)	All children*
	- Sleep and screen time habits	All children*
Demographic and environment	- Socioeconomic status	All children
	- School environment	All schools
	- Neighborhood and family environment (questionnaire)	All children*
	- Infrastructure and sports equipment (Vouzela Municipal Sports Charter)	All equipments

*=Data collected only at baseline¸**=Data collected only at cohort 3; BMI: body mass index; BFM: body fat mass; HDL-C: high-density lipoprotein-cholesterol

Table 4 shows the prevalence for categorical data of weight status, gestation information, hand preference, metabolic risk indicators, physical activity and sleep habits. There were no significant differences between girls' and boys' weight status ($p>0.05$). Further, no differences were found between sexes in gestational information with the exception of boys with overweight at birth ($p=0.027$). A high prevalence of girls (≈60%) did not meet the MVPA recommendations (60 minutes·day^{-1}), while ≈74% of boys did. Effects sizes as marked by the ϕ coefficient are usually very low with the exceptions of meeting, or not, the MVPA recommendations, as well as left hand preferences.

Table 5 shows the school characteristics indicating that the number of students varied substantially. Most schools were located in rural areas. The majority had policies and practices for PA. All schools had playgrounds and no obstacles in the playground areas. There dimensions mostly had more than 70 m^2. Only five schools had a sport center and three of them with more than 50 m^2. Fifteen schools had only one infrastructure, and all had equipment for PA. The duration of PE classes ranged from 45 to 60 minutes, and the time children spent active varied from 30 to 50 minutes. All schools had graduated Physical Education (PE) teachers offering the same physical education opportunities to all students (the official PE program is designed and offered by the City-Hall Educational Department).

Table 3: Descriptive characteristics for continuous data to anthropometry, motor coordination, physical activity, cognitive performance and sleep habits among Vouzela boys and girls at baseline [ANCOVA F-tests and p-values and eta square (η_p^2)].

	Girls			Boys					
	n	Mean	SD	n	Mean	SD	F	p-value	η_p^2
Anthropometry									
Height (cm)	178	123.8	11.4	170	123.2	11.8	3.086	0.080	0.009
Weight (kg)	178	28.0	8.3	170	27.1	8.2	0.002	0.960	0.000
Sitting height (cm)	178	67.1	5.3	170	66.8	5.7	1.563	0.212	0.005
Waist circumference (cm)	178	57.7	7.1	170	57.6	6.0	0.386	0.535	0.001
BFM (kg)	128	8.2	4.0	107	7.1	4.2	4.465	**0.036**	0.019
Gestational information									
Gestational age (weeks)	163	38.6	1.7	156	38.8	1.9	1.095	0.296	0.003
Nº of consultations during pregnancy	90	5.8	1.5	80	5.9	2.1	0.352	0.554	0.002
Birth weight (kg)	173	3.2	0.5	166	3.3	0.5	8.008	**0.005**	0.023
Length at birth (cm)	170	48.2	2.6	162	48.7	2.9	3.118	0.078	0.009
Cephalic perimeter (cm)	135	33.9	1.4	134	34.4	1.6	8.089	**0.005**	0.030
Gross Motor coordination									
WB (points)	153	35.9	14.6	138	32.3	14.5	3.670	0.056	0.013
HH (points)	153	24.7	13.4	138	28.7	16.1	16.09	**<0.001**	0.053
JS (points)	153	41.0	14.2	138	41.6	14.0	1.707	0.192	0.006
MS (points)	153	30.5	7.1	138	30.2	7.4	0.000	0.999	0.000
TGMC (points)	153	132.0	41.3	138	132.8	42.5	1.275	0.260	0.004
Physical fitness									
1-mile run/walk (min)	107	11.4	2.2	93	10.0	2.4	20.65	**<0.001**	0.095
50-yard dash (s)	121	10.1	1.2	107	9.6	1.5	12.44	**0.001**	0.052
Standing long jump (cm)	178	98.4	27.4	170	104.7	29.0	23.70	**<0.001**	0.064
Handgrip (kg)	178	9.8	4.9	170	10.0	5.3	6.895	**0.009**	0.020
Shuttle-run (s)	173	14.3	2.1	167	14.0	2.2	5.205	**0.023**	0.015
Physical activity									
Light (min)	145	259.9	48.8	130	259.6	51.3	0.282	0.596	0.001
Moderate-to-vigorous (min)	145	28.3	8.6	130	38.0	11.6	62.84	**<0.001**	0.188
Cognitive performance *									
Intelligence	28	98.2	10.5	23	99.1	13.4	0.132	0.718	0.003
Metabolic Risk indicators									
SBP ($mm \cdot Hg^{-1}$)	42	107.9	11.0	29	109.1	7.6	0.427	0.516	0.006
DBP ($mm \cdot Hg^{-1}$)	42	64.4	9.7	29	62.6	7.9	1.111	0.296	0.016

HDL-C ($mg \cdot dL^{-1}$)	42	48.8	12.0	29	51.4	14.3	0.608	0.438	0.009
GLU ($mg \cdot dL^{-1}$)	41	86.7	5.9	27	88.5	8.2	1.531	0.220	0.023
TRI ($mg \cdot dL^{-1}$)	42	73.9	37.4	29	58.7	22.1	3.564	0.063	0.050
Sleep habits									
Average weekly time (h)	127	10.0	0.7	121	10.0	0.7	0.041	0.840	0.000
Average weekend time (h)	127	10.8	0.9	121	10.6	0.9	3.183	0.076	0.013

BFM: body fat mass; WB: walking backwards; HH: hoping for height; JS: jumping sideways; MS: moving sides; TGMC: total gross motor coordination (sum of all test scores); min: minutes; s: seconds; h: hour; SBP: systolic blood pressure; DBP: diastolic blood pressure; HDL-C: high-density lipoprotein-cholesterol; GLU: fasting glucose; TRI: triglycerides.

Table 4: Prevalence of weight status, gestational information, hand preference, metabolic risk indicators, physical activity and sleep habits [Chi-square tests (χ^2), p-values and Phi (ϕ) coefficient].

	Girls			Boys					
	n	%	95% CI	n	%	95% CI	χ^2	p-value	ϕ
Weight Status (BMI)									
Normal weight	108	60.7	53.1-67.7	116	68.2	60.7-75.0	2.167	0.141	-0.08
Overweight	45	25.3	19.1-31.9	33	19.4	13.8-25.7	1.722	0.189	0.07
Obesity	25	14.4	9.3-19.5	21	12.4	7.8-17.7	0.217	0.641	0.02
Gestation Information									
Gestation age: Premature	24	14.7	9.7-20.5	21	13.5	8.5-19.2	0.105	0.746	0.02
To term	129	79.1	72.1-85.0	120	76.9	69.5-83.2	0.229	0.632	0.03
Post term	10	6.1	2.9-10.3	15	9.6	5.5-14.7	1.337	0.248	-0.06
Pregnancy complications	29	17.7	12.2-23.9	26	17.2	11.6-23.6	0.012	0.914	0.01
Born complications	38	21.8	15.9-28.3	33	20.0	14.2-26.4	0.173	0.677	0.02
Use of medication and drugs	27	16.5	11.1-22.5	23	15.2	9.9-21.4	0.089	0.756	0.02
Type of gestation: Normal	145	84.3	80.0-89.3	146	90.2	84.5-94.2	2.520	0.112	-0.09
At risk	27	15.7	10.6-21.5	16	9.9	5.8-14.9	2.520	0.112	0.09
Type of birth: Normal	121	69.5	62.1-76.1	104	63.0	55.2-70.2	1.608	0.205	0.07
Caesarean	53	30.5	23.7-37.5	61	37.0	29.6-44.5	1.608	0.205	-0.07
Birth weight : Low weight	16	9.3	5.4-14.0	8	4.8	2.1-8.6	2.526	0.112	0.09
Normal	152	87.9	82.0-92.3	144	86.8	80.6-91.4	0.095	0.758	0.02
Overweight	5	2.9	1.0-5.9	14	8.4	4.7-13.1	4.921	**0.027**	-0.12
Hand Preference (DHQ)									
Right hand	173	97.2	93.6-99.1	165	97.1	93.3-99.0	0.005	0.941	<0.00
Left hand	5	2.8	0.01-0.06	5	2.9	0.01-0.06	0.005	0.941	-0.47
Physical activity									
<60 ($minutes \cdot day^{-1}$)	86	59.3	50.1-66.0	34	26.2	18.8-34.0	30.639	**<0.001**	0.33
≥60 ($minutes \cdot day^{-1}$)	59	40.7	32.6-48.8	96	73.8	65.4-81.0	30.639	**<0.001**	-0.28

Average weekly sleep time									
<10 hours·day^{-1}	48	37.8	29.3-46.4	48	39.7	30.9-48.5	0.092	0.762	-0.02
≥10hours·day^{-1}	79	62.2	53.2-70.4	73	60.3	51.0-68.8	0.092	0.762	0.02

BMI: body mass index; DHQ: The Dutch Handedness Questionnaire.

Table 5: Descriptive statistics of the school environment.

Schools (n=19)	Mean ± SD	Min - Max
School Characterization		
School size		
Number of children	23 ± 22	5 – 87
Number of teachers	4 ± 3	1-8
Ratio teachers/students	0.13 ± 0.11	0.05 – 0.55
	n (%)	
School setting		
Rural	12 (63.2)	
Semi-urban	7 (36.8)	
Policies and Practices for PA		
Policies and practices	10 (52.6)	
Policies	5 (26.3)	
Practices	4 (21.1)	
Physical Structure of the School		
Playground		
Yes	19 (100)	
No	0 (0)	
Playground area		
With obstacles	19 (100)	
Without obstacles	0 (0)	
Playground dimension		
Smaller (10m^2 to 39m^2)	2 (10.5)	
Medium (40m^2 to 69m^2)	4 (21.1)	
Large (>70m^2)	13 (68.4)	
Multi-sports roofed		
Yes	5 (26.3)	
No	14 (73.7)	
Number of Infrastructure		
One Infrastructure	15 (78.9)	
Two Infrastructure	4 (21.1)	
Equipment for PA		
Yes	15 (78.9)	
No	4 (21.1)	
Physical Education Classes		
Duration of PE classes		
45 minutes	6 (31.6)	
60 minutes	13 (68.4)	
Active in PE classes		
30 minutes	6 (31.6)	
40 minutes	4 (21.1)	
50 minutes	9 (47.3)	
Human Resources		
Academic Degree (all graduated)	19 (100)	

PA: physical activity; PE: physical education

Discussion

In very general terms, the majority of variables from the nine domains showed relatively similar age-adjusted averages in boys and girls. Few reached statistical significance ($p<0.05$). For example, the findings for BFM is consistent with existing reports showing that, on average, girls after six years of age have a greater increase in BFM than boys, and this trend is observed until adolescence (Malina et al. 2004). Sex-differences in birth weight favoring boys is consistent with previous data (Morrison 1972; Alcantra and Marcondes 1974; Malina et al. 2004).

Wide reaching longitudinal studies with children covering their multiple individual characteristics as well as their living contexts (family, school and neighborhood) are scarce. We were able to localize eleven methodological papers using a longitudinal design, but only six connected children´s and adolescent´s growth to health markers. From these, only three exclusively concentrated on childhood as their developmental time window: the IDEFICS (Ahrens et al. 2011) is a multicenter prospective cohort study sampling 2 to 9 years old children from nine European countries aiming to investigate the causes of diet- and lifestyle-related diseases and disorders, and its longitudinal part only covers a 2 year period; the ALPASC (Golding et al. 2001) aims to determine ways in which individual genotype combines with environmental pressures to influence health and development sampling 10.000 children and their parents, from early pregnancy until children are 9 years of age; the CATCH (Cairney et al. 2015) study aims to investigate the pathways connecting developmental coordination disorder (DCD), as the primary outcome, to physical activity, physical fitness, and body composition from early to middle childhood. CATCH is a prospective cohort study with 600 children (300 with DCD and 300 controls), initially aged 4 or 5 years at baseline and followed consecutively for four years.

Although with a different scope, the uniqueness of the GMDC-Vouzela Study rests in a series of aspects: (i) its foundation is largely centered on the ecological systems theory of development (Bronfenbrenner 1979) with the multilevel model as the statistical framework (Hedeker and Gibbons 2006); (ii) the sets of predictors are large in scope, namely individual dynamic predictors of GMC and cognitive functions, as well as school settings, teachers, parents and neighborhoods; (iii) the wide range of children´s ages from 4 to 11 years old covering kindergarten (4 to 6yrs), primary school (6-7 to 9-10 yrs), and the entry of preparatory cycle (10-11 yrs); (iv) the use of a mixed-longitudinal design combining several cohorts, and periods of overlap, allowing for a quicker data collection and results availability; (v) reduction of sampling drop-out, financial costs and cumulative effects of re-testing; (vi) the possibility of estimating age, cohort and measurement periods effects in the analysis of GMC and cognitive functions changes (Bell 1953, 1954; Prahl-Andersen and Kowalski 1997), and lastly (vii) the suitable meeting of the theoretical model, the temporal design and the statistical methods will allow the GMDC-Vouzela Study to provide important information to motor development researchers, education professionals and parents for future intervention programs, to identify children at risk, as well as to provide them with adequate remedial programs.

Our results showed that boys´ and girls´ GMC adjusted means were similar; yet, in the HH test boys outperformed girls ($p<0.05$). Existing information about sex-specific coordination performance is relatively inconsistent. For example, a cross-sectional study of Portuguese children (from the Madeira Islands) (Freitas et al. 2015) showed that boys scored better on MS tests but girls scored better on JS tests. In Peruvian children, Valdivia et al. (2008) found a significant difference between sexes in HH and MS favoring boys, and in WB favoring girls. However, using a multilevel modeling approach, Chaves et al. (2015) reported that even when adjusting GMC results for PA and PF, as well as school characteristics, boys were significantly more coordinated than girls. In any case, it seems that sex differences in HH test may be linked to boys´ higher level of expertise in fundamental skills as well as in their higher PF levels (Barnett et al. 2016).

It is well-known that, on average, boys are more physically fit than girls (Malina 2014). Our baseline results corroborated this finding and are in line with Portuguese children data reported by Roriz De Oliveira et al. (2014), namely that boys outperformed girls in all PF tests with the exception of sit-and-reach. These differences between the sexes has been attributed to differences in body size and higher fat-free mass favoring boys (Malina et al. 2004).

There is a continuous urge for children to comply with the WHO daily physical activity recommendations, notwithstanding the fact that a great number of children worldwide fail to achieve this goal (WHO 2010). In our study, boys´ compliance (73.8%) was much higher than girls, although the latter compliance rate was 40.7%. It has been documented that boys are systematically more active than girls (Trost et al. 2002; Telford et al. 2016), maybe because of social roles attributed to boys´ participation in games and tasks that involve higher physical engagements (Malina et al. 2004; Vella et al. 2014), and becausebiological reasons seem to favor them (Wickel et al. 2009).

Although genes play an important role in modulating children growth and developmental (Bouchard et al. 1997), the environment also plays a significant part (Chaves et al. 2012). Since children spend most of their awake time within the family setting as well as in the school environment, it has been suggest, for example, that parents, siblings, equipment and dimension of playground influence their behavior and development (Erwin et al. 2007).

The GMDC-Vouzela Study is not without limitations. Vouzela is a county located in the center of Portugal, and is not representative of all Portuguese counties, nor is its sample size. As such, generalizations of our results need care. Yet, Vouzela´s children overweight/obesity prevalences, as well as birth weights were similar to other Portuguese studies (Viveiro et al. 2016). Considering the intelligence assessments, we were only able to test a smaller sample because it is time consuming, financially demanding and can only be done by chartered psychologists by law. Another limitation involved financial reasons that restricted the data collect on metabolic risk factors in all children, since we only concentrated on those who were overweight and obese. Nevertheless, this study has also some unique points. First, the adopted design allowed us to collect data from 4 to 11 years old children in just three years. Second, the sample covers three important time windows in children development (kindergarten, primary school and preparatory school). Third, the extended and comprehensive set of variables collected in children, schools, families and neighborhoods. Four, most of them are time-varying allowing for more extensive investigation of children´s growth and development as well as causes for individual differences. Five, the overall study embedded in the Ecological Systems Theory, which provides a unique template for research in human development.

Conclusions

This paper presents the main aims, methods and design of the GMDC-Vouzela Study, as well as baseline results in variables from nine domains. In summary, boys and girls had similar age-adjusted mean values on almost variables. Yet, girls had more body fat mass than boys. Boys were significantly heavier at birth and outperformed girls in hopping high coordination test. They were also more physically fit and more active. Future reports will present detailed longitudinal results highlighting the dynamic relationships between children biological and environmental characteristics as well as their lifestyle traits that most likely affect their growth, motor and cognitive development in so many ways. The knowledge generated from this study will not only answer fundamental questions related to pathways among them, but may also generate useful information for future interventions within the Educational domain.

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Disclosure statement

The authors are responsible for the writing and content of the paper. The authors report no conflicts of interest.

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CAPÍTULO III

ARTIGOS ANALÍTICOS

Artigo II

Modelling the dynamics of children´s growth. The Vouzela study on growth, motor development and cognition

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ABSTRACT

The study models children's growth in height, weight and body mass index; investigates sex-differences; probes the effects of socioeconomic status, weight and length at birth and weight and length gains at 18 months of age in these markers of growth; and examine children´s markers of growth trajectories within international references. A total of 314 Portuguese children of different age-cohorts were followed consecutively for three years using a mixed-longitudinal design. Height, weight, body mass index, birth weight, length at birth, weight and length gains at 18 months and socioeconomic status were assessed. A multilevel model was used and all analyses were done in SPSS 24 and SuperMix v1. Boys and girls trajectories do no significant differ in height and weight. Length at birth (β=1.04±0.11, p<0.001) and length gains at 18 months (β=1.04±0.11, p<0.001) were associated with height. There is evidence for a non-linear trend in weight (β=0.24±0.03, p<0.001) and body mass index (β=0.05±0.02, p=0.001). Birth weight and weight length gains at 18 months were statistically significant (β=2.02±0.35, p<0.001; β=1.63±0.16, p<0.001, respectively). In body mass index all predictors used previously were statistically significant. Socioeconomic status and cohorts effects were not related to any markers of growth, and school random effects were not statistical significant. In conclusion, children trends in height, weight and BMI are within normal ranges. Those with higher birth length and weight, and with greater length and weight gains at 18 months tend to be taller, heavier and with greater BMI. Socioeconomic statuses and schools are not associated with their growth trajectories in height, weight and BMI.

Keywords: Child; growth; longitudinal; multilevel analysis

Introduction

Physical growth in childhood and adolescence is marked by a plethora of systematic changes in size, shape, proportions and composition (Tanner 1962, Roche and Sun 2005). Further, height, weight and body mass index (BMI) are probably the most important markers of children growth (WHO 1995), and these are known to be influenced by genetic factors (Thomis and Towne 2006, Visscher 2008) as well as by environmental stimuli (Ulijaszek 2006, Wells and Stock 2011).

Growth is usually described in terms of distance and velocity curves (Tanner, Whitehouse et al. 1966, Kuczmarski, Ogden et al. 2002), resulting from mathematical models (Preece and Baines 1978, Molinari and Gasser 2004) are available. Yet, children growth varies in timing and tempo that are highly visible in different segments of their body (Roche and Sun 2005). Additionally, a broader understanding of the dynamics of children growth must also consider perinatal factors as important predictors of rates of changes (Wells 2017), and these may have long-term consequences during their lifespan (Hack, Schluchter et al. 2003, Linsell, Johnson et al. 2018). For example, longitudinal studies have shown that birth weight (BW) and length at birth (LB) were related to differences in children growth (Hack, Schluchter et al. 2003, Rogers, Ness et al. 2006, Wells, Chomtho et al. 2007). Further, rapid weight gains in infancy and childhood have been associated with increased risk of obesity in childhood and adulthood (Karaolis-Danckert, Buyken et al. 2006, Baidal, Locks et al. 2016).

The impact of environmental factors in children growth and development are well-known (Eveleth and Tanner 1990, Schell, Gallo et al. 2009, Artiningrum, Suryobroto et al. 2014). A recorrent theme centers around the influence of socioeconomic status (SES) (Clarke, O'malley et al. 2008, Morgen, Mortensen et al. 2010, Howe, Tilling et al. 2012, Silva, van Rossem et al. 2012, Silverwood, Williamson et al. 2016). For example, Howe, Tilling et al. (2012) showed that socioeconimic differences had no impact in early infancy growth, but lightly faster growth in later childhood results in minimal widening of the height inequality.

Further, Silva, van Rossem et al. (2012) reported that compared to children of high SES, those of low SES showed an accelerated linear growth until the18th month of life, overcompensating their initial height deficit.

The school context is the most organized and structured institution also favoring children growth and development (Morgan, Barnett et al. 2013). There, children spend most of their day studying, playing, doing systematic physical exercises through regular physical education (PE) classes, eating as well as learning some of the fundamentals of healthy living. This net of experiences may have some influence in children growth and development, mainly in their weight and BMI trajectories. Further, we contend that to investigate the dynamics of children growth, we should simultaneously consider important individual correlates as well as their contexts. Thus, the aims of the present paper are: (1) to describe the dynamics of children growth in height, weight and and BMI; (2) to investigate possible differences in boys´ and girls´ growth trajectories; (3) to explore the effects of socio-economic status (SES) in these growth markers, as well as (4) the influence of weight and length at birth and weight and length gains at 18 months of age in children growth; and (5) to examine children´s height, weight and BMI trajectories within international references.

Material and methods

Sample

Data for the present paper comes from the research project entitled *Growth, Motor Development and Cognition Study (GMDC- Vouzela Study)* conducted in the Vouzela County, central region of Portugal. This research has a mixed-longitudinal design, and its main aim is to investigate the dynamic relationship between physical growth, motor and cognitive development of children aged 4 to 11 years old. Children from six age-cohorts, with a two-year overlap, were recruited and were followed consecutively for three years - 2013-2014, 2014-2015, 2015-2016 [for details see Reyes, Chaves et al. (2018)]. All were enrolled in 19 schools of Vouzela County and were invited to participate in the project; the response rate was ~90%, resulting in an overall sample of 485 children. Written informed consent was obtained from the parents and/or legal guardians and the project was approved by Vouzela´s educational, political and health authorities, as well as by the Ethics Committee of the Faculty of Sport, University of Porto (CEFADE 01.2016). The present paper will only rely on 314 children from all cohorts aged 4 to 11 years old (165 girls, 149 boys) (but see Table 1), because we will consider those with complete data in all variables. All children with special needs were excluded from this study (n=24). In addition, we tested for differences in a set of variables (sex, age, BW, LB, weight and length absolute gains from 0 to 18 months and SES) to identify possible differences between children with complete information and those with missing data. Minor differences were found in age (0.56 yrs), birth weight (0.11 kg), and length at birth (0.60 cm) favoring those included in the analysis.

Table 1. Cohorts, overlapping years, and total number of children per cohort.

Cohorts	Ages of follow-up								Total
Cohort 1	4	5	6						60
Cohort 2		5	6	7					59
Cohort 3			6	7	8				57
Cohort 4				7	8	9			50
Cohort 5					8	9	10		49
Cohort 6						9	10	11	39
									314

Gestational Information

Gestational information was obtained from children´s health booklets and confirmed by nurses from the Vouzela health-center registry. In the present paper, we only consider data from birth weight (kg) (BW) and length at birth (cm) (LB), as well as weight and length absolute gains from 0 to 18 months.

Anthropometry

Height and weight were collected following the protocols of the International Society for the Advancement of Kinanthropometry (Ross and Marfell-Jones 1991). Height was measured using a portable stadiometer (Holtain

Ltd, Crymych, United Kingdom) having children without shoes and with their head positioned in the Frankfurt plane. Weight was measured with children wearing light clothing using a TANITA portable bioelectrical impedance scale (TANITA BC-418MA Segmental Body Composition Analyzer, Tanita, Corporation, Japan). Body mass index (BMI) was calculated using the usual formula, BMI=body weight (kg)/height (m)^2.

Socioeconomic status

The Portuguese school social support system, based on an index budget reference developed by the Portuguese Ministry of Education (Ministério da Segurança Social e do Trabalho 2003) for families, provides information that allowed to divide families´ socioeconomic status (SES) in three levels: (i) level A: up-to 2.934 €·year^{-1}, where children get books and feeding supports (lunch at school); (ii) level B: from 2.934 to 5.896 €·year^{-1}, with half of level-A support; (iii) level C: ≥5.897 €·year^{-1} implies no support.

Data Quality Control

The data quality control was carried out in different stages: (1) retesting a random sub-sample of children on each measurement day over the three consecutive years; (2) computing the technical error of measurement (TEM), such that TEM=0.2 cm for height and 0.1 kg for weight; (3) checking for data entry to identify possible punching errors and verify for the presence of outliers.

Statistical Analysis

Descriptive statistics (means, standard deviations and percentages) were calculated in SPSS 24.0. A multilevel modeling approach was used (Hedeker and Gibbons 2006) since data has a nested structure - repeated observations nested within subjects which are nested within schools. As advocated by Hedeker and Gibbons (2006), the time metric was centered at 4 years of age (time 0), such that 0, 1, 2, 3, 4, 5, 6 and 7 corresponds to 4, 5, 6, 7, 8, 9, 10 and 11 years of age. SuperMix v.1 software (Hedeker, Gibbons et al. 2008) was used, and all model parameters were simultaneously estimated using a maximum likelihood technique. Further, models were tested sequentially: Model 1 (M_1) described the best developmental trajectory for height, weight and BMI using age, age^2, sex, age-by-sex and age^2-by-sex interactions as predictors as well as random components at children and school-levels; in Model 2 (M_2) covariates like BW, and LB, length gain (LG), weight gain (WG), and SES were added as well as cohort effects given the two-year overlap of our sample design. Further, as is current in this statistical methodology (Hedeker and Gibbons 2006), goodness of fit will be marked by the Deviance statistic. We will then compare M_1 with M_2 for their better fit to the data, and the best model will show a statistically significant lower Deviance. The significant level was set at 5%.

Results

Boys and girls descriptive statistics (mean±SD or percentages) are in Table 2. As expected, there was a clear trend for increasing height, weight and BMI with increasing age. On average, boys had apparently higher BW as well as LB. The same seems to occur in weight and length gains from birth until 18 months of age. SES level C (≥5.870 €·year^{-1}) was the most frequent.

Growth trends in height, weight and BMI, as well as their interactions with sex, show specificities which are unique to each (Table 3). In height, there is apparently no trend for acceleration (β=0.007±0.02, p=0.78), although there is a significant effect of the interaction with sex (β=-0.07±0.03, p=0.03). Yet, at 4 years of age, boys and girls do not differ in their mean heights (β=1.10±0.09, p=0.09). In weight, there is evidence of a curvilinear trend (β=0.23±0.03, p<0.001), as well as an interaction with sex (β=-0.08±0.04, p=0.04). As with height, boys and girls show no mean differences in their weight at 4 years of age (β=0.01±0.56, p=0.90). BMI shows a clear curvilinear trend (β=0.05±0.02, p=0.003), with no statistically significant differences in boys´ and girls´ developmental trajectories. School random effects were not statistically significant (p>0.05) in any of the growth markers, and because of this will be removed in the next model. Further, significant children heterogeneity in height, weight and BMI at 4 years of age were noticed (height σ^2=18.03±2.10, p<0.001; weight σ^2=8.47±1.31, p<0.001, BMI σ^2=3.95±0.54, p<0.001) as well as in their developmental trajectories (height σ^2=0.33±0.10, p=0.001, weight σ^2=1.62±0.21, p<0.001, BMI σ^2=0.21±0.04, p<0.001).

Model 2 results are in Table 4. In height, the instantaneous growth velocity was estimated to be 6.37 cm·year^{-1} and no significant differences were noticed in boys´ and girls´ trajectories. No statistically significant cohort effects were identified, and the same occurred for children with different SES. Further, children with greater LB (β=1.04±0.11, p<0.001) as well as showing greater LG at 18 months (β=0.79±0.08, p<0.001) are those who show, on average, greater growth velocities. In weight there is evidence for a curvilinear trend (β=0.24±0.03, p<0.001) with no significant differences in boys´ and girls´ trajectories, although at 4 years of age boys were lighter than girls (β=-1.22±0.50, p=0.01). In weight, no cohort or SES significant effects were found in WG from 4 to 11 years of age. On average, greater weight gains across age were positively related to BW (β=2.02±0.35, p<0.001), as well as WG at 18 months (β=1.63±0.16, p<0.001). As with height and weight, no statistically significant cohort and SES statuses were noticed in children BMI trajectories. The curvilinear BMI trend is evident (β= 0.05±0.02, p=0.001); further, children with higher BW and LB as well as those with greater LG and WG at 18 months are those that show, on average, greater BMI gains from 4 to 11 years of age. Consistent with M_1, there are significant differences in children height, weight and BMI values at 4 years of age, as well as in their respective developmental trajectories, since the variances are all statistically significant. Finally, M_2 fits the data better than M_1 for height ($\chi^2_{(8)}$=112,02, p<0.001) weight ($\chi^2_{(8)}$=111,78, p<0.001) and BMI ($\chi^2_{(10)}$=99,15, p<0.001).

Figure 1 contrasts mean heights, weights and BMI of Vouzela´s children with the international reference centile charts (Kuczmarski, Ogden et al. 2002). In general, boys and girls mean heights are at 75th percentile; weight and BMI, in boys and girls, were between the 75th and the 90th percentiles.

Table 2. Descriptive statistic (mean ± SD or percentage) for girls (n=165) and boys (n=149) across the study years

	Girls							
	4 years (n=32)	5 years (n=52)	6 years (n=67)	7 years (n=76)	8 years (n=80)	9 years (n=75)	10 years (n=43)	11 years (n=22)
Anthropometry								
Height (cm)	105.3 ± 5.4	111.7 ± 5.6	119.0 ± 5.3	124.6 ± 5.7	130.9 ± 5.7	136.7 ± 5.9	142.8 ± 6.4	149.2 ± 6.1
Weight (kg)	18.8 ± 3.8	21.0 ± 3.5	24.5 ± 4.6	27.6 ± 6.2	31.8 ± 8.0	35.8 ± 8.5	39.5 ± 8.8	45.5 ± 7.5
BMI ($kg \cdot m^{-2}$)	16.8 ± 2.1	16.8 ± 1.8	17.2 ± 2.3	17.6 ± 2.8	18.4 ± 3.4	19.0 ± 3.4	19.2 ± 3.5	20.4 ± 3.3
Gestational Information								
Birth weight (kg)	3.1 ± 0.4	3.0 ± 0.5	3.1 ± 0.5	3.1 ± 0.5	3.1 ± 0.4	3.2 ± 0.5	3.2 ± 0.5	3.3 ± 0.5
Length at birth (cm)	48.0 ± 1.6	47.6 ± 2.0	47.8 ± 2.1	47.6 ± 2.1	47.6 ± 2.3	47.7 ± 2.4	48.0 ± 2.7	48.5 ± 2.1
Weight at 18 months (kg)	10.9 ± 1.3	10.7 ± 1.3	10.8 ± 1.4	10.9 ± 1.2	11.0 ± 1.2	11.1 ± 1.2	11.2 ± 1.3	11.2 ± 1.1
Length at 18 months (cm)	81.7 ± 3.3	81.5 ± 3.4	80.3 ± 3.4	80.1 ± 3.3	79.7 ± 3.1	80.3 ± 3.6	80.4 ± 4.0	81.3 ± 4.5
Weight absolute gain (kg)	7.8 ± 1.9	7.8 ± 2.0	7.7 ± 1.2	7.8 ± 1.1	7.8 ± 1.2	7.9 ± 1.2	7.8 ± 1.2	7.9 ± 1.0
Length absolute gain (cm)	33.7 ± 3.1	34.0 ± 3.3	32.5 ± 3.4	32.5 ± 3.4	32.1 ± 3.4	32.6 ± 3.7	32.4 ± 4.2	32.8 ± 4.6
Socioeconomic status								
A (up-to 2.934 €·$year^{-1}$)	18.8%	19.2%	16.4%	23.7%	22.5%	26.7%	20.9%	27.3%
B (2.934 to 5.896 €·$year^{-1}$)	25.0%	28.8%	31.3%	36.8%	28.8%	26.7%	23.3%	27.3%
C (≥5.870 €·$year^{-1}$)	56.3%	51.9%	52.2%	39.5%	48.8%	46.7%	55.8%	45.5%
	Boys							
	4 years (n=28)	5 years (n=56)	6 years (n=68)	7 years (n=65)	8 years (n=67)	9 years (n=59)	10 years (n=40)	11 years (n=14)
Anthropometry								
Height (cm)	105.4 ± 3.7	113.0 ± 4.7	118.8 ± 4.8	125.4 ± 5.4	131.5 ± 6.7	137.4 ± 6.4	142.9 ± 7.5	147.3 ± 5.8
Weight (kg)	18.2 ± 2.3	21.8 ± 3.2	23.8 ± 3.7	27.2 ± 4.7	30.4 ± 6.9	34.5 ± 7.4	38.3 ± 9.7	42.5 ± 7.1
BMI ($kg \cdot m^{-2}$)	16.3 ± 1.4	17.0 ± 2.0	16.9 ± 2.2	17.2 ± 2.4	17.4 ± 2.9	18.1 ± 2.9	18.6 ± 3.4	19.5 ± 2.6
Gestational Information								
Birth weight (kg)	3.1 ± 0.6	3.3 ± 0.7	3.3 ± 0.6	3.4 ± 0.5	3.2 ± 0.6	3.2 ± 0.6	3.1 ± 0.6	3.2 ± 0.3
Length at birth (cm)	48.4 ± 2.7	48.7 ± 2.5	48.6 ± 2.4	48.6 ± 2.2	47.9 ± 2.9	48.1 ± 2.9	47.9 ± 3.2	48.6± 1.8
Weight at 18 months (kg)	11.2 ± 1.5	11.6 ± 1.4	11.6 ± 1.2	11.7 ± 1.1	11.6 ± 1.2	11.7 ± 1.3	11.7 ± 1.4	11.9 ± 1.0
Length at 18 months (cm)	80.9 ± 2.7	82.2 ± 3.3	82.1 ± 3.5	82.4 ± 3.4	82.2 ± 3.5	81.8 ± 3.3	81.9 ± 3.4	81.4 ± 3.8
Weight absolute gain (kg)	8.1 ± 1.2	8.3 ± 1.1	8.3 ± 1.1	8.3 ± 1.1	8.4 ± 1.2	8.4 ± 1.3	8.6 ± 1.3	8.7 ± 1.1
Length absolute gain (cm)	32.6 ± 2.7	33.4 ± 3.0	33.5 ± 3.5	33.8 ± 3.5	34.2 ± 3.8	33.7 ± 3.6	34.0 ± 3.8	32.8 ± 3.7
Socioeconomic status								
A (up-to 2.934 €·$year^{-1}$)	25.0%	19.6%	13.2%	15.4%	13.4%	15.3%	7.5%	7.1%
B (2.934 to 5.896 €·$year^{-1}$)	17.9%	17.9%	23.5%	20.0%	23.9%	27.1%	37.5%	57.1%
C (≥5.870 €·$year^{-1}$)	57.1%	62.5%	63.2%	64.6%	62.7%	57.6%	55.%	35.7%

Table 3. Parameter estimates (standard-errors) for fixed and random effects for height, weight and BMI (Model 1).

	Height	Weight	BMI
Regression coefficients (fixed effects)			
Intercept (4 years)	105.62 (0.61)***	18.78 (0.44)***	16.75 (0.25)***
Age (velocity)	6.33 (0.18)***	2.21 (0.22)***	0.15 (0.12)^{ns}
Age^2 (acceleration)	0.007 (0.02)^{ns}	0.23 (0.03) ***	0.05 (0.02)**
Sex (boys)	1.10 (0.09)^{ns}	1.01 (0.56)^{ns}	-0.18 (0.35)^{ns}
Age-by-sex	0.13 (0.26)^{ns}	0.13 (0.31)^{ns}	-0.05 (0.17)^{ns}
Age^2-by-sex	-0.07 (0.03)*	-0.08 (0.04)*	-0.01 (0.02)^{ns}
Variance components (random effects)			
School Level			
Intercept	2.49 (0.09)^{ns}	0.60 (0.52)^{ns}	-0.01 (0.08)^{ns}
Child Level			
Intercept	18.03 (2.10)***	8.47 (1.31)***	3.95 (0.54)***
Age	0.33 (0.10)**	1.62 (0.21)***	0.21 (0.04)***
Covariance (intercept/age)	1.0 (0.36)**	0.68 (0.42)^{ns}	-0.002 (0.13)^{ns}
Residual Level			
Intercept	1.42 (0.11)***	1.57 (0.17)***	0.54 (0.04)***
Model Summary			
Deviance	3996.15	4114.47	3049.51
Number of estimated parameters	11	11	11

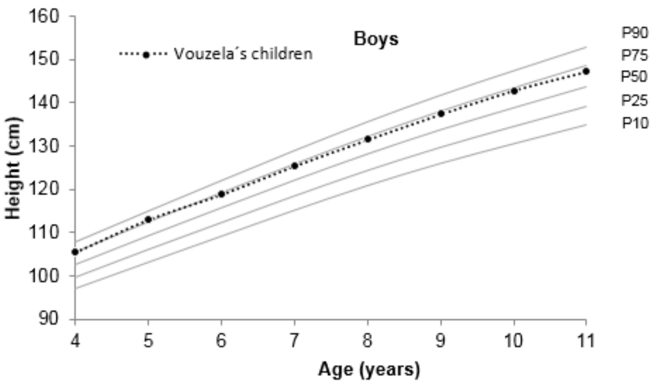
ns=non-statistically significant; * p<0.05; ** p<0.01; *** p<0.001

Table 4. Parameter estimates (standard-errors) for fixed and random effects for height, weight and BMI (Model 2).

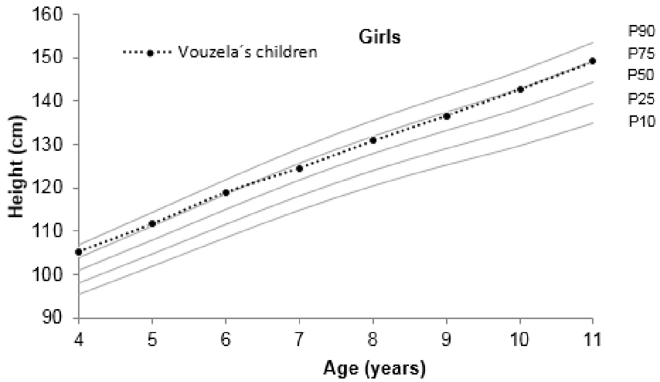
	Height	Weight	BMI
Regression coefficients (fixed effects)			
Intercept (4 years)	105.60 (0.67)***	19.11 (0.62)***	17.05 (0.34)***
Age (velocity)	6.37 (0.19)***	2.12 (0.25)***	0.10 (0.12)^{ns}
Age^2 (acceleration)	0.004 (0.03)^{ns}	0.24 (0.03)***	0.05 (0.02)**
Sex (boys)	-0.23 (0.61)^{ns}	-1.22 (0.50)*	-0.81 (0.31)**
Age-by-sex	0.04 (0.26)^{ns}	0.06 (0.30)^{ns}	-0.02 (0.16)^{ns}
Age^2-by-sex	-0.06 (0.04)^{ns}	-0.07 (0.04)^{ns}	-0.01 (0.02)^{ns}
CE_c2_1	0.46 (0.52)^{ns}	0.07 (0.46)^{ns}	-0.11 (0.25)^{ns}
CE_c3_2	0.56 (0.72)^{ns}	-0.29 (0.72)^{ns}	-0.33 (0.36)^{ns}
CE_c4_3	0.12 (0.82)^{ns}	0.11 (0.88)^{ns}	0.02 (0.42)^{ns}
CE_c5_4	-0.57 (0.83)^{ns}	0.23 (0.91)^{ns}	0.12 (0.43)^{ns}
CE_c6_5	-1.39 (0.72)^{ns}	-1.19 (0.79)^{ns}	0.29 (0.38)^{ns}
Birth weight (kg)		2.02 (0.35)***	1.67 (0.31)***
Weight absolute gain (kg)		1.63 (0.16)***	1.04 (0.11)***
Length at birth (cm)	1.04 (0.11)***		-0.26 (0.08)***
Length absolute gain (cm)	0.79 (0.08)***		-0.13 (0.08)**
SES (level B)	0.65 (0.73)^{ns}	0.63 (0.56)^{ns}	0.14 (0.34)^{ns}
SES (Level C)	0.11 (0.65)^{ns}	0.54 (0.49)^{ns}	0.14 (0.30)^{ns}
Variance components (random effects)			
Child Level			
Intercept	13.96 (1.70)***	4.80 (0.91)***	2.26 (0.38)***
Age	0.38 (0.10)***	1.50 (0.20)***	0.17 (0.04)***
Covariance (intercept/age)	0.22 (0.34)^{ns}	0.22 (0.36)^{ns}	0.07 (0.11)^{ns}
Residual Level			
Intercept	1.37 (0.11)***	1.65 (0.13)***	0.58 (0.04)***
Model Summary			
Deviance	3884.13	4002.69	2950.36
Number of estimated parameters	19	19	21

BMI= body mass index; CE=cohort effects; CE_c2_1 is the overlapping effect of cohort 2 on cohort 1; SES= socioeconomic status; ns=non-statistically significant; * $p<0.05$; ** $p<0.01$; *** $p<0.001$

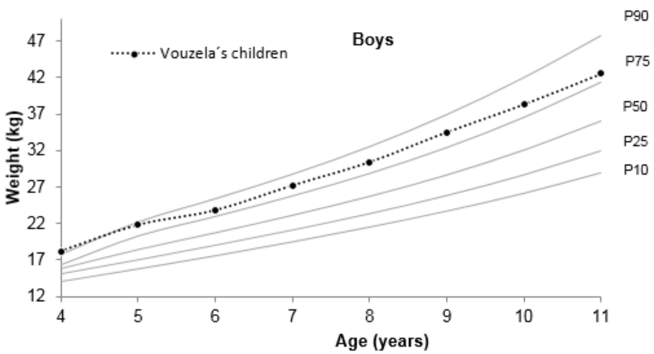
A)


Boys
Vouzela´s children
Height (cm)
Age (years)
P90
P75
P50
P25
P10

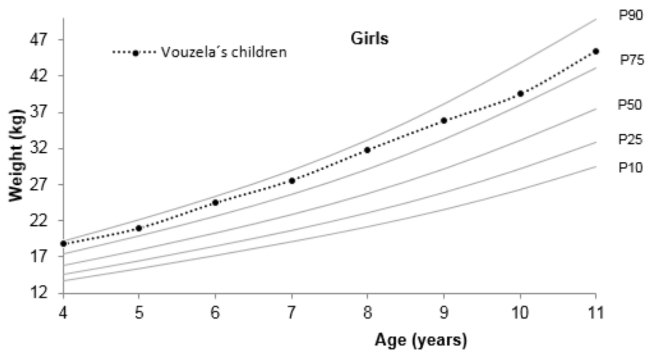
D)


Girls
Vouzela´s children
Height (cm)
Age (years)
P90
P75
P50
P25
P10

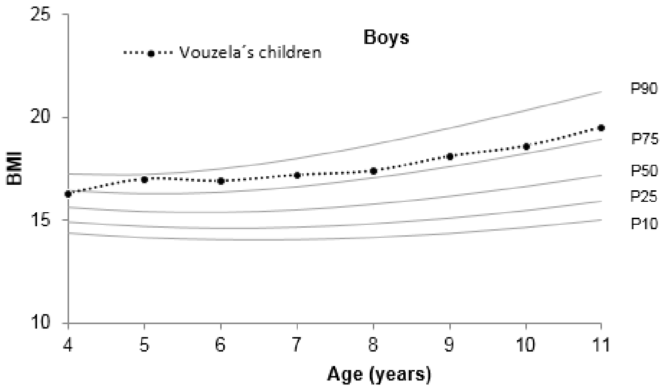
B)


Boys
Vouzela´s children
Weight (kg)
Age (years)
P90
P75
P50
P25
P10

E)


Girls
Vouzela´s children
Weight (kg)
Age (years)
P90
P75
P50
P25
P10

C)



F)

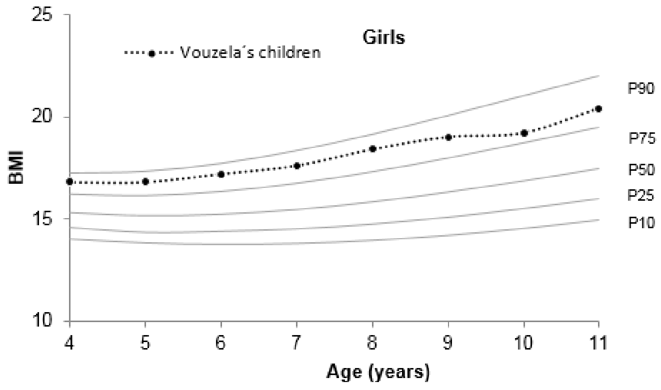


Figure 1. Plotting of Vouzela´s children height, weight and BMI within CDC reference charts**.**

Discussion

This study investigated children´s growth longitudinal trajectories in height, weight and BMI. Sex-differences, as well as the effects of SES, weight and length at birth and weight, and at 18 months of age in these markers of growth were also analyzed. In Model 1, we reported that primary school-children changes in height, weight and BMI exhibited a curvilinear trajectory. These results are apparently similar to other non-statistically modelled longitudinal accounts expressed in centile charts for this period of age (Tanner, Whitehouse et al. 1966, Kuczmarski, Ogden et al. 2002).

At 4 years old, no sex-differences were noticed in height, weight and BMI. However, there is a systematic tendency for girls to surpass boys in their height and weight trends. These differences are well-know, and they are most probably related to girl´s earlier mid-growth spurt and their adolescent spurt (Gasser, Müller et al. 1985), as well as by hormonal influences (estrogen) which begins to function earlier in girls, preparing them for menarche (Riggs, Khosla et al. 2002, Wells 2007).

Vouzela´s schools seemingly do not explain any amount of significant variation in children´s height, weight and BMI trajectories. This may be mostly due to the fact that there is not much variation across schools in their nutritional habits, healthy conditions, physical and built environments. Of the 19 schools in Vouzela, 15 of them (~80%) have a group that supervises or gives guidance (for example, a health team and/or school action) on those practices and policies. All schools have qualified PE teachers and have similar materials for their classes.

In model 2, we added predictors (cohort effects, SES, LB and LG at 18 months in height; BW and BG at 18 months) in all three-growth markers and a little different growth developmental narrative appeared the best developmental trajectory for growth. Trend in height it is now linear and there is no more significant interaction of age^2-by-sex in height and weight. Boys were lighter than girls at 4 years and had lower BMI values.

Given the mixed-longitudinal nature of the design, cohort effects were modelled and tested, as advocated by Prahl-Andersen and Kowalski (1973), because it is possible that histories and children´s growth and developmental histories within each age-cohort, may have differently impacted their growth trends. However, not statistically significant impact was identified for these effects.

We also did not find any relationship between children´s SES and their growth trajectories, and available information of this association is inconsistent. For example, Howe, Tilling et al. (2012), using data from the ALSPAC study, examined 12366 English children growth conditional on their socioeconomic pattering. Socioeconomic differences in childhood growth were small, and only resulted in minimal widening of the height variation with increasing age. Also, socioeconomic differential in height during childhood arises largely through inequalities in LB, with small increases in the inequality from differences in growth in later childhood. Yet, Silva, van Rossem et al. (2012), using data from the Generation R Study, from 2972 Dutch mothers and their children, studied maternal education level as a measure of SES and its association with repeatedly measured at 2 months, 6 months, 14 months and 25 months of age. They found that at 2 months, children in the lowest education subgroup were shorter than those in the highest. Between 1 and 18 months, they grew faster than their counterparts did. By 14 months, children in the lowest educational subgroup were taller than those in the highest. In conclusion, compared with children of high SES, those of low show an accelerated linear growth until 18th month of life, leading to an overcompensation of their initial height deficit. Vouzela´s characteristics, as the predominance of a rural and a semi-urban city, maybe are responsible for not finding differences in the SES effect, even if there is SES inequality, the action of the public power can reach all social strata.

Length at birth and LG at 18 months were positively related with children´s height trajectories, and the same occurred to BW and WG. Jointly, BW and WG were also positively related to children´s BMI trajectories and LB and LG were negatively associated. These results are in agreement with previous research. For example, Rogers, Ness et al. (2006) investigated how weight and length at birth were associated with subsequent lean and total body fat in 6086 (3080 girls) children aged 9-10-y-old. The results showed that higher Ponderal index at birth (weight/length^3) was related with both higher fat and lean mass in childhood bur also with an increase in the fat-to-lean mass ratio. Also, Wells, Hallal et al. (2005) tested if prenatal growth (BW or ponderal index) and postnatal WG (during infancy and childhood) were associated with body composition in later childhood in 172 Brazilian boys. As a result, BW was correlated with later height and lean mass, but not fatness; weight gain 0-6 months was correlated with later height, lean mass and BMI, but not with fatness. Also, weight gain 1-4 yrs was associated with later fatness and LM; and weight gain 4-9 yrs was strongly associated with fatness but not LM. The Vouzela´s health center has great concern and caution regarding pregnant women and their newborns. The majority of them had more than five consultations during pregnancy, thus following the growth of the baby and future problems. For example, of all the children evaluated in this study and with gestational information, only 35 had low birth weight.

The last purpose of the present study was to examine children´s height, weight and BMI trajectories within international references. Children´s weight and BMI mean values were located between the 75^{th} and the 90^{th} percentiles of the international growth references by age and sex (Kuczmarski et al. 2000). This is important information for parents, educators and Vouzela´s authorities since childhood overweight and obesity has systematically grown during the last decades and are global challenges (Lindholm, Bergman et al. 2018) with adverse consequences for their current health (Lakshman, Elks et al. 2012, Llewellyn, Simmonds et al. 2016).

This study is not without limitations. First, as our sample is not representative of the whole country and care must be taken with generalization of the results. Second, we do not have data about children´s nutritional habits, which could be linked to their weight gains.

Conclusions

Children trends in height, weight and BMI are within ranges of international normative values. Further, those with higher birth length and weight, with greater length and weight gains at 18 months tend to be taller, heavier and with greater BMI. Children socioeconomic statuses are not associated with their growth trajectories in height, weight and BMI. Schools do not have any exploratory power in Vouzela´s children differences in their weight and BMI changes across time.

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Declaration of Interest Statement

None of the authors reported conflict of interest.

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Artigo III

Modelling the dynamics of children's gross motor coordination

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ABSTRACT

This study modelled children's gross motor coordination, investigated sex-differences and identified the effects of fixed and dynamic correlates on motor coordination development. A total of 344 Portuguese children (170 girls), from 6 age cohorts (5 to 9 years of age), were followed consecutively for three years (age range 5 to 11 years) using a mixed-longitudinal cohort design. Birth weight, hand dominance and socioeconomic status (SES) were identified. Gross motor coordination, body mass index, physical fitness (PF) and physical activity (PA) were assessed annually. A sequence of multilevel hierarchical linear models were developed. Model 1 found that age, age^2, sex, sex-by-age and sex-by-age^2 were significant predictors ($p<0.05$) of gross motor coordination. Boys outperformed girls from 6 years of age onwards. Model 2 found a cohort effect ($p<0.05$). Model 3 found that right handers were more coordinated ($p<0.05$). When the confounders of body mass index, PF and PA were added to the model (Model 4) it was found that boys and girls had parallel trajectories in their gross motor coordination development. In conclusion, children with increasing body mass index were less coordinated, while those who were stronger and more agile had steeper trajectories of gross motor coordination with age.

Keywords: Children; gross motor coordination; longitudinal study; multilevel modelling analysis

Introduction

It has been shown that the efficiency with which children perform their daily activities is related to their motor competence (Hands, 2008), with gross motor coordination recognized as one of the important facets of motor competence (Robinson et al., 2015). A plethora of cross-sectional research (e.g., Chaves et al., 2016; Luz et al., 2018; Söğüt, 2016), as well as systematic reviews (Barnett et al., 2016; Cattuzzo et al., 2016), have tried to better elucidate why children differ in their gross motor coordination. In general**,** more coordinated children tend to be more physically fit (Fransen et al., 2012), as well as more physically active (Graf et al., 2004), whilst lower levels of fundamental movement skills are associated with overweight and/or obesity (Lubans, Morgan, Cliff, Barnett, & Okely, 2010). It has also been reported that age, sex, and socioeconomic status (SES) play important roles, although with different effect sizes (Barnett, et al., 2016). Hand dominance has also been linked with gross motor coordination, with right handers being more coordinated than left handers (Gabbard, Hart, & Gentry, 1995). Additionally, intrauterine growth has been related to gross motor coordination development, with gestational issues and low birth weight shown to impair subsequent motor development, especially motor coordination (Brown, Burns, Watter, Gibbons, & Gray, 2015; Maggi, Magalhães, Campos, & Bouzada, 2014).

As indicated, most available studies of gross motor coordination are cross-sectional in nature; however, longitudinal data is needed to better elucidate the dynamics of a child's gross motor coordination development and its manifold correlates. Available longitudinal studies using the *KöperkoordinationsTest für Kinder (*KTK) test battery are scarce. They come primarily from Germany (Ahnert, Schneider, & Bös, 2009; Willimczik, 1980), Belgium (Vandorpe et al., 2012) and Portugal (Antunes et al., 2016; Deus, Bustamante, Lopes, Silva, & Maia, 2010) and vary substantially in their scope, design, methodology and data analysis, with results not always comparable. For example, Willimczik (1980) investigated German children followed consecutively from 6 to 10 years of age and found girls outperformed boys at baseline; however, by 9 years of age boys caught-up and surpassed girls performances. In contrast, recent data from Deus, et al. (2010) studying Portuguese children, followed consecutively from 6 to 9 years of age, reported no specific sex-effects in any of the four KTK battery tests. D'Hondt et al. (2014) showed that Belgian children's gross motor coordination levels were negatively influenced by their weight status; further, physical activity (PA) at baseline was not significantly related to initial gross motor coordination performance. Similarly, in the mixed-longitudinal study by Deus, et al. (2010), with 285 (142 girls) Azorean children aged 6 to 10 years old, higher levels of body mass index were associated with lower coordinative performance as children aged. In contrast with D'Hondt, et al. (2014), more physically active children were more coordinated (Deus, et al., 2010).

It is therefore contended that a more extensive and integrated investigation into children's gross motor coordination development is required, which include concurrent effects of a child's dynamic and fixed predictors. One important predictor to be considered in this dynamic is the school context, since it is the most organized and structured institution for children's development (Morgan et al., 2013). Using Bronfenbrenner's (1979) ecological approach as a template, a mixed-longitudinal study in primary schools was designed to better elucidate why children differ in their gross motor coordination development. In the present paper a "stepwise" modelling strategy is employed to address the following aims: (1) to model children's gross motor coordination intraindividual changes, and to investigate whether children diverge in their developmental trajectories; (2) to investigate possible developmental sex-specific trajectories; (3) to determine if hand dominance, SES and / or low birth weight influences gross motor coordination development, and (4) to probe the effects of time-varying covariates (those changing alongside gross motor coordination) namely PA, physical fitness (PF) and body mass index on children's gross motor coordination development. We hypothesised that development would be non-linear and that trajectories would be greater in boys. Further, hand dominance, SES, birth weight, body mass index, PA and PF would all have independent significant time dependant effects on gross motor coordination development.

Materials and methods

Sample

Data comes from the Growth, Motor Development and Cognition Study carried out in Vouzela County (GMDC-Vouzela study, a central region of Portugal. In brief, this research project is grounded in Bronfenbrenner ecological systems theory (Bronfenbrenner, 1979), has a mixed-longitudinal cohort design and aims to investigate the dynamic relationships between growth, motor performance, behaviour and cognition in children from ages 4-to-11 years. The study design is described in detail elsewhere (Reyes et al., 2018). In brief, six age-cohorts (4 to 9 years of age), were recruited and children were followed consecutively for three years (2013-2014; 2014-2015; 2015-2016), resulting in a two-year overlap between cohorts (see Table 1). In the present study children were considered from all cohorts; however, since gross motor coordination was only assessed from 5 years onwards, 4 year old children were not part of the analysis. Using a convenient cluster sampling strategy (schools and children), we collected data from 411 children (~90% response rate) aged 5-to-11 years, from 19 public schools; from these, 35 children (8.5%) dropped out (five were from cohort 2, seven from cohort 3, eleven from cohort 4, nine from cohort 5, and three children from cohort 6). Further, the missing data was presumed to be missing at random. Additionally, we investigated whether children with missing data differed from those with complete data across a set of variables (sex, gross motor coordination, birth weight, height, weight, laterality, PF, PA, SES) and found that only standing long jump and shuttle-run tests significantly favored children used in the analysis. In summary, the present study consists of 344 children (170 girls and 174 boys) with complete data (gross motor coordination and all covariates) at any given time point (Table 1). Written informed consent was obtained from parents or legal guardians. The Ethics Committee of the Faculty of Sport, University of Porto, as well as Vouzela´s educational, political and health authorities approved the project.

Table 1. Cohorts, overlapping years, and total number of children per cohort.

Cohorts	Ages of follow-up							Total
Cohort 1	4	5	6					37
Cohort 2		5	6	7				63
Cohort 3			6	7	8			58
Cohort 4				7	8	9		60
Cohort 5					8	9	10	62
Cohort 6						9	10	11	64
								344

Gross Motor Coordination

Gross motor coordination was assessed using the *KöperkoordinationsTest für Kinder* battery (KTK) of tests; developed in Germany (Kiphard and Schilling, 1974). The battery comprised four tests: (1) walking backwards on balance beams. The children were asked to walk backwards three times on each of three (6 cm, 4.5 cm and 3 cm width) balance beams (3 m length, 5 cm height). The total successful steps (maximum 8) for each balance beam, in every attempt, was computed; (2) hopping for height on one leg. Children hopped over a pile of pillows (60 cm x 20 cm x 5 cm each) without touching any, and continue hopping on the same foot at least 2 times to have a successful hop. The height was increased by adding one pillow at a time and the child had 3 attempts at each height and with each foot – the successful hop on the first trial corresponded to 3 points, on the second to 2 points and on the third trial to 1 point. Three trials for each leg at each height were recorded. A maximum of 78 points (39 per leg) could be achieved; (3) jumping sideways. The child was asked to jump laterally and consecutively over a wooden slat (60 cm x 4 cm x 2 cm), with both feet, as fast as possible for 15 seconds. The task was repeated twice and the number of jumps, over the two trials, was summed; (4) moving sideways. The child stood with both feet on a box (25 cm x 25 cm x 5.7 cm) and placed both hands on an adjacent box (25 cm x 25 cm x 5.7 cm). Then, they place the second box alongside the first and stepped on it, this movement was repeated over 20 seconds, as fast as possible, in two trials – the number of relocations were recorded (2 points). After the two trials the number of relocations was summed. The sum of scores from each test was used as a measure of total gross motor coordination (GMCS) as suggested by Schilling, one of the KTK developers (Schilling, 2015).

Birth weight

A specific questionnaire, developed by the Vouzela´s educational and health authorities in conjunction with the researchers of the Faculty of Sport, University of Porto, was used to obtain the child's gestational information. Examples of information collected were: gestational age, birth weight, number of consultations during pregnancy, length at birth, cephalic perimeter and use of medicine. We also consulted children's health booklets by the Vouzela health-center registry to confirm mothers´ information. However, for this article only birth weight is presented.

Anthropometry

Height was measured without shoes, using a portable stadiometer (Holtain, UK), holding the child's head, in the Frankfurt plane; the accuracy was 0.1 cm. Body mass (kg) was measured with children in light clothing and with a 0.1 kg precision using a portable bioelectrical impedance scale (TANITA BC-418 MA Segmental Body Composition Analyzer; Tanita, Corporation, Japan). Body mass index was calculated using the formula: body mass (kg)/height (m)^2.

Laterality - Manual Preference

A short version of the Dutch Handedness Questionnaire (van Strien, 2003) was used to assess hand dominance. This consists of simple daily tasks where children self-report which hand they preferred to use, for example, "to pick up a pencil or hold a toothbrush". In young children, it is recommended to use the objects mentioned in the questionnaire to carry out the tasks. For each task it was indicated whether the child used their right hand, the left hand or if there was no preference. Children were classified with left hand preference and right hand preference according to procedures outlined in the questionnaire. In the analysis, left hand preference was the reference category.

Physical Fitness

Components of performance-related PF were assessed using three tests from the American Alliance for Health Physical Education, Recreation and Dance (AAHPERD, 1980) test battery: (1) explosive leg power - standing long jump test: children jumped with both feet together as far as possible and results were expressed in cm; (2) static strength - handgrip strength: children squeezed a hand held dynamometer (Takei Physical Fitness Test GRIP-D, Japan) with maximum force over five seconds and results were expressed in kg; (3) agility - shuttle-run test: children ran, as fast as possible, from a starting line to a line nine meters away, where two wooden blocks were placed. They picked up a block (one at time) and returned to the starting line and placed the block on the line. This process was repeated. Results were expressed in $m \cdot s^{-1}$.

Physical Activity

The Actigraph GT3X+ accelerometer (Actigraph, Pensacola, USA) was used to objectively measure PA. All children were instructed to wear the accelerometer for 7 consecutive days (5 week-days and 2 week-end days), and to only remove the device during water activities (i.e, swimming, showering) and when sleeping. The accelerometer was placed on the iliac crest and was held in place by an elastic belt with adjustable clip. The *ActiLife*® software (version 6.5.4) was used to download the recorded data immediately upon retrieval of each accelerometer, and to be considered valid if children had at least 4 days (with at least one weekend day) of data, with a minimum of 10 hours of daily wear time. Any sequence of at least 20 consecutive minutes of zero activity counts was considered non-wear time (Barreira et al., 2015). Different expressions of PA were derived using cut-points developed by Evenson, Catellier, Gill, Ondrak, & McMurray (2008). For the present study, moderate-to-vigorous physical activity (MVPA) was used, defined as all activities greater than 574 counts/15 s epochs, and expressed in $min \cdot day^{-1}$.

Socioeconomic status

Socioeconomic status was obtained according to the Portuguese school social support system; which is based on an index budget reference of the Portuguese Ministry of Education directives (Ministério da Segurança Social e do Trabalho, 2003). Vouzela schools´ administration provided information regarding family levels based on this index: level A (up-to 2.934 €·year^{-1}), and children received books and feeding support (lunch at school); level B (from 2.934 to 5.896 €·year^{-1}) with half of level-A support; level C (≥5.897 €·year^{-1}) implies no support. A dummy code was created, with level A as the reference group.

Data quality control

Data quality control was performed using a series of steps. First, all team members were systematically trained by experts belonging to the Kinanthropometry and Motor Learning Labs from the Faculty of Sport, University of Porto, and were continuously supervised during all assessments by the first author. Second, an in-field reliability approach was used such that during each year of data collection a random sample of ~60 children were retested. Third, reliability estimates were computed using the technical error of measurement (TEM) and ANOVA-based intraclass correlation (R) and corresponding 95% confidence intervals. The TEM was 0.20 cm for height and 0.09 kg for body weight. For gross motor coordination individual tests R values ranged from 0.78 (moving sideways) to 0.91 (walking backwards), and from 0.71 (50-yard dash) to 0.97 (handgrip) for PF tests. Fourth, a check was done regarding errors in data entry, normality of variables´ distributions, and extreme cases.

Statistical analysis

All descriptive statistics and normality tests were performed in SPSS ver 24.0 and included means, standard deviations and percentages. Since the data had a hierarchical structure, i.e., repeated observations nested within children which are themselves nested within schools, a multilevel hierarchical linear model was chosen using a random effects modelling approach (Hedeker and

Gibbons, 2006). The time metric was centred at 5 years of age (corresponding to time 0, to ensure a valid intercept within the age range being observed). Thus, the metric of time of 0, 1, 2, 3, 4, 5, 6, corresponded to 5, 6, 7, 8, 9, 10, 11 years of age. A sequence of models were specified based on our aims: Model 1 (M_1) had 3 levels [repeated observations within individuals (level-1), individuals (level-2), and schools (level-3)], and captured intra-individual changes and inter-individual differences. Predictors used in this model were age, age^2, sex, sex-by-age and sex-by-age^2; the age powers functions allowing for the non-linearity of the data. In Model 2 (M_2) we added cohort effects to test for a mixed-longitudinal design effect (Raudenbush and Chan, 1991). In Model 3 (M_3) the time-invariant predictors, birth weight, manual preference and SES, were added. Finally, a more encompassing model (M_4) included time-varying predictors (body mass index, PF tests and MVPA) was fitted. All predictors were grand-mean centered as advocated by Hox (2010). All parameters were simultaneously estimated based on the full maximum likelihood procedure implemented in the software SuperMix v.1 (Hedeker, Gibbons, du Toit, & Cheng, 2008). This procedure is robust, and all maximum likelihood parameter estimates are precise and consistent. To compare best fitting nested models, the Deviance statistic was used. It is expected that the Deviance drops significantly, adjusting for lost degrees of freedom, if a new model fits the data better than the previous one (Hedeker and Gibbons, 2006). Additionally, residuals were inspected as advocated (Hox, 2010). The significance level was set at 5%.

Results

Descriptive statistics (mean ± SD or percentages) for girls and boys are shown in Table 2. As expected, mean gross motor coordination and PF tests, in both sexes, increased with increasing age. Mean birth weight was relatively similar in both sexes across ages. In girls and boys, mean body mass index increased with age. The mean MVPA had a distinct pattern between the sexes: in girls there was an apparent decrease until 9 years of age and afterwards an increase; in boys, a similar trend seems to occur till 10 years and then an increase. There was a high frequency of right-handed children in both sexes at each age. Children with SES in level C (≥5.870 €·year^{-1}) were more frequent.

Results of the multilevel models are provided in Table 3. In M_1, the GMCS for a 5 year-old was 81.81±3.95 points. On average, the GMCS instantaneous velocity at 5 years was 21.14±2.36 points, the average acceleration was not statistically significant (β=0.33±0.37, P>0.05). Boys showed, on average, a significantly lower GMCS (β=-8.77±4.84, P<0.05) at 5 years of age. The interactions sex-by-age (β=8.40±3.22), and sex-by-age^2 (β=-1.56±0.52) were statistically significant (P<0.05), suggesting a cross-over trajectory of boys´ GMCS, i.e., they catch-up and surpass girls GMCS development at 6 years of age (see Figure 1).

Variance components results showed that schools did not explain why children varied in their GMCS development (σ^2=34.80±28.90, P>0.05). Children showed significant inter-individual differences at 5 years of age (σ^2=446.99±98.06, P<0.05), but no inter-individual different developmental trajectories - they were parallel to their group (sex) trends (σ^2=15.99±12.72, P>0.05). More coordinated children at 5 years of age tended to show greater increases in their GMCS developmental trajectories (σ=56.97±33.35, P>0.05).

Model 2 (M_2) results are adjusted for statistically significant cohort effects given the 2-year overlap of the study design. The main sex-effect was not statistically significant (β=-5.71±4.70, P>0.05), i.e., at baseline (5 years of age), boys and girls have a similar mean value. All other parameter estimates remained similar in their interpretation. There was a significant decrease in Deviance favoring M_2 relative to M_1 (M_1-M_2=6684.96-6659.15=25.81; $\chi^2_{(5)}$=25.81, P<0.001) indicating a better fit of the model.

In Model 3 (M_3) birth weight, manual preference and SES were added as fixed-covariates. Right handers were, on average, more coordinated (β=17.11±5.30, P<0.05); birth weight and SES did not explain differences in children GMCS (P>0.05). All other model parameters had similar interpretation as in M_2. Further, this model fitted the data better than the previous one ($\chi^2_{(4)}$=10.62, P=0.01).

Finally, the last model (M_4) included time-varying covariates, namely body mass index, PF tests and MVPA. With these new adjustments, the sex-by-age and the sex-by-age^2 effects were no longer statistically significant ($P>0.05$) indicating that boys´ and girls´ GMCS developmental trajectories were parallel, i.e., the difference at baseline favoring girls (on average more 11.16 GMCS points than boys) remained constant until 11 years of age (see Figure 2). Further, the average acceleration (age^2) was now significant (β=0.80±0.39, $P<0.05$). For example, at age anchored at 5 years of age (age=0), i.e., at baseline, GMCS average growth rate was 7.14 points·year^{-1} [(7.14+2(0.80) (0)=7.14], at 8 years of age (age=3) the average growth rate is 11.94 points·year^{-1} [(7.14+2(0.80) (3)=11.94], and at 11 years of age (age=6), the average GMCS growth rate is 16.74 points·year^{-1}. All time varying covariates except MVPA, show significant associations with GMCS developmental trajectories. Children with increasing body mass index tend to be less motor coordinated (β=-2.32±0.47, $P<0.05$), while those who are stronger in standing long jump (β=0.43±0.06, $P<0.05$) or hand grip (β=1.35±0.40, $P<0.05$), and those who are more agile (β=27.32±4.11, $P<0.05$) showed greater GMCS in time. This model fits the data better than M_3: $\chi^2_{(5)}$=182.71, $P<0.001$.

Table 2. Descriptive statistics (mean ± SD or percentage) for girls (n=170) and boys (n=174) across the study years.

Tests	Girls						
	5 years (n=23)	6 years (n=56)	7 years (n=70)	8 years (n=74)	9 years (n=83)	10 years (n=47)	11 years (n=21)
Gross Motor Coordination							
GMCS (points)	70.2 ± 19.9	103.0 ± 29.7	129.2 ± 28.6	155.6 ± 31.9	175.9 ± 31.6	207.7 ± 37.0	219.9 ± 42.0
Gestational Information							
Birth weight (kg)	2.9 ± 0.5	3.0 ± 0.5	3.1 ± 0.5	3.1 ± 0.4	3.2 ± 0.5	3.2 ± 0.5	3.4 ± 0.4
Anthropometry							
BMI ($kg \cdot m^{-2}$)	16.7 ± 2.0	16.9 ± 2.0	17.7 ± 2.9	18.1 ± 3.2	18.8 ± 3.2	19.3 ± 3.4	20.6 ± 3.3
Manual Preference							
Right Hand	82.6%	87.5%	88.6%	95.9%	89.2%	91.5%	76.2%
Left Hand	17.4%	12.5%	11.4%	4.1%	10.8%	8.5%	23.8%
Physical fitness							
Standing long jump (cm)	78.9 ± 17.1	94.3 ± 17.8	102.0 ± 16.5	114.4 ± 17.0	123.5 ± 17.0	133.2 ± 17.3	137.2 ± 15.6
Handgrip strength (kg^f)	6.3 ± 1.0	8.0 ± 1.9	10.0 ± 2.6	12.6 ± 2.9	14.3 ± 3.0	16.5 ± 3.2	19.8 ± 3.3
Shuttle run ($m \cdot s^{-1}$)	2.3 ± 0.3	2.5 ± 0.3	2.6 ± 0.2	2.7 ± 0.2	2.8 ± 0.2	2.9 ± 0.3	3.1 ± 0.2
Physical activity							
MVPA ($min \cdot d^{-1}$)	65.3 ± 20.8	62.2 ± 19.6	60.3 ± 17.4	59.6 ± 19.7	55.0 ± 15.3	57.8 ± 18.3	60.2 ± 19.9
Socioeconomic status							
A (up-to 2.934 €·year^{-1})	26.1%	17.9%	20.0%	20.3%	24.1%	21.3%	28.6%
B (2.934 to 5.896 €·year^{-1})	39.1%	37.5%	37.1%	28.4%	27.7%	21.3%	28.6%
C (≥5.870 €·year^{-1})	34.8%	44.6%	42.9%	51.4%	48.2%	57.4%	42.9%
	Boys						
	5 years (n=39)	6 years (n=60)	7 years (n=62)	8 years (n=60)	9 years (n=61)	10 years (n=39)	11 years (n=16)
Gross Motor Coordination							
GMCS (points)	64.1 ± 23.3	102.2 ± 33.2	130.1 ± 37.0	153.1 ± 34.8	177.0 ± 38.3	199.8 ± 29.8	213.8 ± 41.8
Gestational Information							
Birth weight (kg)	3.3 ± 0.6	3.4 ± 0.5	3.4 ± 0.5	3.3 ± 0.5	3.3 ± 0.5	3.3 ± 0.6	3.4 ± 0.4
Anthropometry							
BMI ($kg \cdot m^{-2}$)	16.9 ± 2.0	17.0 ± 2.1	17.1 ± 2.3	17.9 ± 3.6	18.4 ± 3.8	19.0 ± 4.4	19.2 ± 3.0
Manual Preference							
Right Hand	84.6%	93.2%	90.6%	92.3%	93.8%	92.9%	94.1%
Left Hand	15.4%	6.8%	9.4%	7.7%	6.3%	7.1%	5.9%

Physical fitness							
Standing long jump (cm)	82.8 ± 19.8	99.2 ± 19.6	114.1 ± 17.9	121.0 ± 19.0	130.9 ± 17.1	139.0 ± 16.4	143.9 ± 25.8
Handgrip strength (kg^f)	6.6 ± 1.8	9.1 ± 2.4	11.2 ± 2.5	13.5 ± 3.4	15.5 ± 3.4	18.0 ± 4.4	20.2 ± 4.2
Shuttle run ($m \cdot s^{-1}$)	2.4 ± 0.4	2.5 ± 0.3	2.7 ± 0.2	2.8 ± 0.2	2.9 ± 0.2	3.1 ± 0.2	3.1 ± 0.2
Physical activity							
MVPA ($min \cdot d^{-1}$)	83.6 ± 23.8	82.8 ± 21.8	77.3 ± 23.5	74.0 ± 23.4	71.1 ± 20.7	68.5 ± 22.6	70.3 ± 20.1
Socioeconomic status							
A (up-to 2.934 €·year^{-1})	17.9%	13.6%	14.1%	10.8%	14.1%	7.1%	-
B (2.934 to 5.896 €·year^{-1})	20.5%	25.4%	23.4%	24.6%	26.6%	35.7%	52.9%
C (≥5.870 €·year^{-1})	61.5%	61.0%	62.5%	64.6%	59.4%	57.1%	47.1%

GMCS = gross motor coordination score; BMI= body mass index; MVPA= Moderate-to-vigorous physical activity

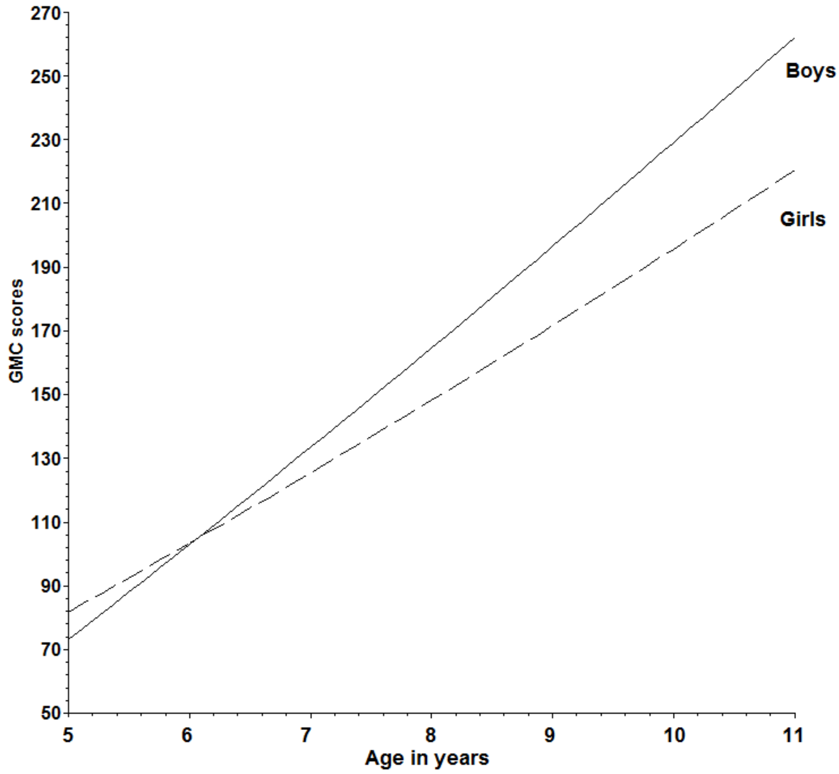

Figure 1. Model 1 GMC scores trend lines for boys and girls

Table 3. Parameter estimates (standard-errors) for fixed and random effects of the four gross motor coordination (GMC) multilevel models

	Model 1 (M_1)	Model 2 (M_2)	Model 3 (M_3)	Model 4 (M_4)
Regression coefficients (fixed effects)				
Intercept (5 years)	81.81 (3.95)***	87.26 (3.89)***	70.22 (6.88)***	111.19 (6.71)***
Age (velocity)	21.14 (2.36)***	17.75 (2.50)***	17.65 (2.52)***	7.14 (2.70)**
Age^2 (acceleration)	0.33 (0.37)	0.71 (0.38)	0.72 (0.38)	0.80 (0.39)*
Sex (boys)	-8.77 (4.84)*	-5.71 (4.70)	-6.96 (4.69)	-11.16 (4.18)**
Sex-by-age	8.40 (3.22)**	7.12 (3.16)*	7.24 (3.15)*	3.88 (2.99)
Sex-by-age^2	-1.56 (0.52)**	-1.42 (0.51)**	-1.43 (0.51)**	-0.94 (0.50)
CE_c2_1		12.43 (4.13)**	12.36 (4.05)**	16.83 (3.40)***
CE_c3_2		27.62 (5.55)***	25.52 (5.59)***	29.74 (4.81)***
CE_c4-3		21.44 (6.14)***	20.05 (6.20)**	25.62 (5.34)***
CE_c5_4		16.30 5.80)**	14.48 (5.92)*	19.95 (5.02)***
CE_c6_5		7.80 (4.50)	7.30 (4.62)	11.34 (3.87)***
Birth weight (kg)			0.83 (3.17)	3.28 (2.54)
Manual preference (right hand)			17.11 (5.30)**	10.20 (4.18)*
SES (level B)			1.72 (4.59)	-1.43 (3.63)
SES (Level C)			2.69 (4.16)	0.84 (3.31)
Body mass index ($kg \cdot m^{-2}$)				-2.32 (0.47)***
Standing long jump (cm)				0.43 (0.06)***
Handgrip strength (kg^f)				1.25 (0.40)**
Shuttle run ($m \cdot s^{-1}$)				27.32 (4.11)***
MVPA ($min \cdot day^{-1}$)				0.03 (0.04)
Variance components (random effects)				
School Level				
Intercept	34.80 (28.90)	7.68 (15.88)	13.16 (18.23)	6.52 (10.43)
Child Level				
Intercept	446.99 (98.06)***	390.28 (90.53)***	336.33 (84.87)***	131.53 (59.76)*
Age	15.99 (12.72)	11.03 (12.35)	10.80 (12.68)	0.94 (10.66)
Covariance (intercept/age)	56.97 (33.35)	71.12 (31.75)*	77.79 (31.28)*	48.84 (25.08)
Residual Level				
Intercept	204.43 (18.18)***	204.75 (17.99)***	205.49 (17.98)***	217.35 (17.88)***
Model Summary				
Deviance	6684.96	6659.15	6648.53	6465.82
Number of estimated parameters	11	16	20	25

CE=cohort effects; CE_c2_1 is the overlapping effect of cohort 2 on cohort 1; SES= socioeconomic status; MVPA= Moderate-to-vigorous physical activity; * P<0.05; ** P<0.01; *** P<0.001.

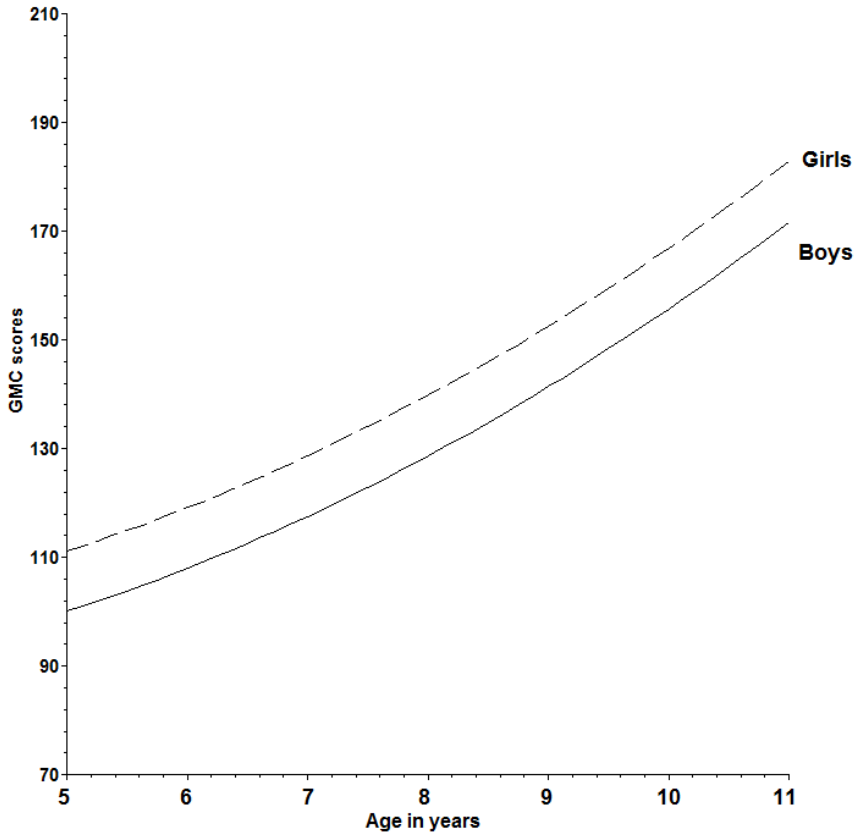

Figure 2. Model 4 GMC scores trend lines for boys and girls

Discussion

This novel study investigated children's gross motor coordination longitudinal trajectories as well as the effects of fixed and time-varying predictors, and found that developmental narratives changed according to the increase of complexity of the model (from M_1 to M_4). In Model 1, children's gross motor coordination development was non-linear, confirming previous longitudinal data from each of the four KTK tests (Deus, et al., 2010), as well as from cross-sectional KTK percentiles charts (Antunes, et al., 2016; Chaves, Tani, Souza, Baxter-Jones, & Maia, 2013). Further, starting at 6 years of age, boys tended to outperform girls, which is consistent with cross-sectional and short-term longitudinal reports (Ahnert, et al., 2009; Chaves, et al., 2016; Lopes et al., 2016). This was also confirmed in the systematic review by Barnett, et al. (2016) which found that being male was a positive correlate of motor competence. The boys´ higher GMCS levels are likely explained by the additive effects of their body size, higher motor skill proficiency (Ré et al., 2017), and possibly more intense and varied non-organized play activities. Since no significant inter-individual differences were identified, boys´ and girls´ GMCS development followed similar paths, i.e., their developmental trajectories were parallel. This can be partially explained by the fact that Vouzela children receive the same opportunities in their physical education classes (which are mandatory, e.g., with minimum of 45 minutes per week), as well as free sport participation incentives promoted by the city-hall policies (City Hall of Vouzela, 2018). These results endorse Hirtz and Holtz (1987) suggestion that motor coordination development depends on the quantity and quality of children’s daily motor experiences. As a final remark on Model 1, no significant school effects were found in children GMCS development. Our novel result may be partially linked to the limited number of schools considered in the study. Yet, during the last five years the Vouzela city-hall provided all schools with many incentives, equipment as well as changes in their architecture, whenever possible, to provide children better places to study and play, and the absence of substantial differences observed among these schools may also be a result of such policies. In any case we concur with Morgan, et al. (2013) that school based programs that include developmentally appropriate fundamental motor skill learning experiences with trained physical education teachers improve children’s proficiency, and this may also extended to gross motor coordination.

Given that our study design is mixed-longitudinal, cohort effects were modelled and tested (Prahl-Andersen and Kowalski, 1973) and this was considered in Model 2, since it is possible that children´s lives and educational histories within each age-cohort, (notwithstanding the two year overlap), may have impacted their GMCS development. The main results in this Model remain similar to M_1, even when adjusted for this significant methodological constraint. In Model 3, fixed covariates (birth weight, hand dominance, SES) were added and results remained similar to M_2, even when only hand dominance was statistically significant ($P<0.05$). Although there is consistent evidence of the adverse effects of birth weight on children´s physical, motor and cognitive development (Maggi, et al., 2014; Oliveira, Magalhães, & Salmela, 2011; Victora et al., 2008), available studies linking gross motor coordination and birth weight are scarce. For example, Tchamo, Moura-dos-Santos, dos Santos, Prista, & Leandro (2017) found that low birth weight children only had an adverse performance in the moving sideways KTK test, but Moura-Dos-Santos et al. (2014) did not report any significant influence of birth weight on gross motor coordination performance. Available data linking hand dominance and motor coordination are also scarce and inconsistent. For example, using cross-sectional data, Giagazoglou, Fotiadou, Angelopoulou, Tsikoulas, & Tsimaras (2001) and Gabbard, et al. (1995) found that right-handers were more coordinated than left-handers, whereas Rousson, Gasser, Caflisch, & Jenni (2009) did not report a similar trend for limb preference. One possible explanation for the results favoring right-handers in our sample can be linked to the “right-handers based world” hypotheses (Porac and Coren, 1981) which states that the physical environment favors them. Conversely, it imposes an adjustment to the left-handers, forcing them to use their non-preferred hand in performing their daily life tasks. Thus, the preferred hand of the left-handers may lose some functionality over the preferred hand of right-handers.

Although Vandendriessche et al. (2012), with a sample of 1955 Flemish children 6-11 years of age, found that more coordinated Flemish girls had higher SES, Antunes, et al. (2016) using data from 158 Portuguese children (75 girls) assessed continuously at 6, 7, 8 and at 12, 13 and 14 years of age, reported that those with lower SES were more proficient in coordinative tasks. Valdivia et al. (2008) on the other hand, did not show a conclusive relationship using information from 4007 Peruvian children (1889 girls) aged 6 to 11 years old from Lima metropolitan area. Even though SES inequality is present in Vouzela County, all children regardless of their SES had the same opportunities for developing their fundamental motor skill and gross motor coordination within the mandatory school physical education classes, as well as freely available sports practice opportunities favored by the city-hall facilities, and this may in part explain our results.

With the inclusion of time-varying covariates in M_4 (body mass index, PF, and PA) a different GMCS developmental narrative emerged. Though GMCS trends remained non-linear, girls outperformed boys and this advantage was consistent across time. This is in apparent contrast to a previous systematic review which found boys´ were more skilled than girls for motor competence (Barnett, et al., 2016). Although this review is based on empirical data, the sex-differences in motor competence and fundamental motor skill were not adjusted for the additive effects of dynamic predictors that significantly affect boys´ and girls´ performance. The main reason for girls´ favored performance is that GMCS trajectories have been partialled-out of the dynamic effects of body mass index, PF and PA that usually favor boys. Similar results were reported with longitudinal data from Azorean children (dos-Santos et al., 2018).

Body mass index was inversely related to gross motor coordination to changes in time, which corroborates Belgian (D'Hondt et al., 2013; D'Hondt, et al., 2014) longitudinal data. D'Hondt, et al. (2013) investigated the short-term change in gross motor coordination levels according to children´s weight status and explored the influence of putative factors predicting their gross motor coordination performance over a 2-year interval. They assessed 50 overweight children as well as 50 normal-weight children and they were matched for sex and age. Further, D'Hondt, et al. (2014), with 2517 children aged 5-13 years old, investigated the relationship between children´s weight status and level of gross motor coordination over time, taking baseline PA into account as a possible mediator. The explanation is apparently simple; since gross motor coordination tasks require the displacement of center of mass, children with higher body mass index across time are expected to perform more poorly than their peers. On the other hand, more physically fit children tend to display higher GMCS across time. A similar finding was reported with Azorean children followed longitudinally.

There is evidence showing positive associations between gross motor coordination and fundamental motor skill with PF, namely with cardiorespiratory endurance and muscular strength/endurance (Cattuzzo, et al., 2016; Robinson, et al., 2015). Zaichkowsky, Zaichkowsky, & Martinek (1980) suggested that the efficiency with which children performed their various daily activities depend, in some way, on their levels of balance, flexibility, strength and agility, and we concur with dos-Santos et al (2018) that stronger and more agile children tend to display, across time, higher gross motor coordination levels. Additionally, Robinson, et al. (2015) in their systematic review reported low-to-moderate positive relationships between motor competence (marked by fundamental motor skill and/or by gross motor coordination) and PA during childhood. However, available cross-sectional data using gross motor coordination as a dependent variable and PA as a predictor are limited. For example, Krombholz (1997) and Graf, et al. (2004), both used sports participation as a putative marker for children's PA and reported that those with higher sports participation levels were also more likely to be more coordinated. Moreover, a recent report by Laukkanen, Pesola, Finni, & Sääkslahti (2017) found that in Finnish boys´ as well as in Finnish girls´ MVPA was not significantly associated with their gross motor coordination levels. Additionally, we were only able to retrieve two longitudinal reports, with more than two time points, that investigated the effects of PA on children's gross motor coordination developmental trajectories, and their results are divisive. Both reports used the same data set from Azorean children and relied on the Godin and Shephard (1985) questionnaire to assess PA. Deus, et al. (2010) found that children with higher levels of gross motor coordination also had higher PA levels, yet, dos-Santos, et al. (2018) also considered the joint effects of PF, and these "overruled" the PA effects in gross motor coordination. This was exactly what we found. Even though more active children (in terms of their MVPA) may be more coordinated, this link apparently loses its "strength" when PF enters in the equation. In other words, PF is more important than PA in terms of gross motor coordination levels.

This study is not without limitations. First, care must be taken with generalization of the results as our sample is not representative of the whole country. Yet, to our understanding, almost no gross motor coordination longitudinal study achieved this level of generalization. Second, despite being consistently used across many countries, the KTK battery has a limited number of tasks and does not map all coordination domains. However, to our knowledge, no gross motor coordination test battery achieves this level of universality. Third, the number of schools is reduced and this may have caused its variance to be non-significant. Also, theoretical simulation studies within multilevel models are always highly specific to initial conditions, and generalizations are not universal.

Conclusions

Children's gross motor coordination development is non-linear. Starting at 6 years of age boys tend to outperform girls, even when significant cohort effects are considered. Schools have no apparent relationship to children's differences in gross motor coordination. Further, right handers tend to be more proficient in their coordination tasks, but socioeconomic status as well as weight at birth have no effect on children's developmental trajectories. In time, stronger and more agile children also tend to be more coordinated, although body mass index development impairs increases in children motor coordination. Moderate-to-vigorous physical activity has no significant effect on children's gross motor coordination across the years. Considering the joint effects of these covariates, girls tend to outperform boys in their motor coordination development.

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Declaration of Interest Statement

None of the authors have report any conflicts of interest.

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Artigo IV

Examination of children's physical fitness trajectories using a comprehensive multilevel modelling approach

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ABSTRACT

Objectives: To model children's physical fitness development and investigate both sex-differences and the effects of fixed and dynamic correlates.

Design: Mixed-longitudinal.

Methods: A total of 348 Portuguese children (177 girls) in six different age-cohorts were followed consecutively for three years. Physical fitness tests (handgrip strength, standing long jump and shuttle run), birth weight, body mass index, gross motor coordination, physical activity and socioeconomic status were annually assessed. Data were analysed longitudinally using multilevel models.

Results: Between 4 and 11 years boys outperformed girls in all three physical fitness tests. Birth weight was positively associated with shuttle run (β=-0.18±0.09, $p<0.05$). Body mass index was positively associated with handgrip strength (β=0.35±0.04, $p<0.001$) and shuttle run (β=0.06±0.01, $p<0.001$), but negatively associated with standing long jump (β=-0.93±0.23, $p<0.001$). Gross motor coordination was positively associated with all three physical fitness tests while physical activity was associated with standing long jump (β=0.08±0.02, $p<0.05$) and shuttle run (β=-0.003±0.002, $p<0.05$) only. No school effect was found and socioeconomic status was not related to any physical fitness tests.

Conclusions: Children physical fitness development showed a non-linear trend with increasing age, with boys outperforming girls. Schools and socioeconomic status had no effects in explaining differences in children physical fitness. Children born with higher birth weight were stronger and more agile; further, those with higher BMI were less agile but stronger. More coordinated children were more physically fit, more active and presented greater development in explosive leg strength and agility.

Keywords: Child; physical fitness; longitudinal; multilevel analysis

Introduction

Physical fitness (PF) can be defined as the efficiency of bodily systems and functions to perform in a variety of contexts [1] and is considered a marker of health status [2]. Differences in children PF levels are explained by a variety of genetic and environmental factors [3]. Moreover, there is evidence from cross-sectional data that PF is positively associated with physical activity (PA) [4], birth weight [5], gross motor coordination (GMC) [6], and socioeconomic status (SES) [7]. Additionally, school location, size, and facilities are also thought to influence children's PF [8]. But, to tease out the independent effects of PA, birth weight, SES, GMC and school on PF development longitudinal data are required.

However, few studies have examined children PF changes beyond two time points. For example, Ruedl, Franz, Frühauf, Kopp, Niedermeier, Drenowatz, Greier [9] reported that overweight boys and girls physical fitness development was lower than their non-overweight peers. Further, Rodrigues, Stodden, Lopes [10] described different rates of change in various PF and motor competence variables and found that children with low or average rates of change in their fitness and motor competence were more likely to become overweight or obese by the end of primary school, regardless of their sex or initial body mass index (BMI). Additionally, Bai, Saint-Maurice, Welk [11] reported that higher SES and school size were associated with better PF profiles. Notwithstanding the importance of these studies, they did not consider other potential PF correlates that may impact longitudinal trajectories of PF, nor did they consider the multilevel data structure [9] of the school context [10], or the time dependent effects of PA or GMC [11].

The Growth, Motor Development and Cognition study (GMDC-Vouzela) [12] was initiated to address previous limitations. The purposes of this paper are three-fold: (1) to model intra-individual PF developmental trajectories and identify the magnitude of inter-individual differences; (2) to investigate the effects of time-invariant (sex, birth weight and SES), as well as (3) time-varying (age, BMI, GMC and PA) covariates on children´s PF development.

Methods

The Growth, Motor Development and Cognition study (GMDC) was a mixed-longitudinal study carried out in Vouzela, a central region of Portugal between 2013 and 2016 [12]. Data was initially collected in six age-cohorts who were followed for three consecutive years (4-6 years, 5-7 years, 6-8 years, 7-9 years, 8-10 years, 9-11 years). All children from the 19 schools of the region were invited to join the study and the participation rate was ~90%. Children with special needs were excluded (n=24) from the analysis. Written informed consent was obtained from parents and the project was approved by local authorities and the ethics committee of the Faculty of Sport, University of Porto.

Apart from 4 year-old children, data from all cohorts (n=348, 177 girls) were considered with complete data on all variables (Table 1). In addition, we tested for differences in a set of variables (sex, age, PF tests, birth weight, BMI, GMC, PA and SES) to identify putative differences between completers and those with missing data (n=150, 75 girls). Differences were only found in BMI, shuttle-run test and SES favoring those included in the analysis ($p<0.05$).

Table 1. Number of children per cohort and age group.

Cohorts	Ages of follow-up								Total
Cohort 1	4	5	6						41
Cohort 2		5	6	7					65
Cohort 3			6	7	8				58
Cohort 4				7	8	9			59
Cohort 5					8	9	10		58
Cohort 6						9	10	11	67
									348

Physical fitness was assessed using three tests: (i) handgrip strength (HG in kg) - assessed via hand held dynamometry (Takei Physical Fitness Test GRIP-D, Japan) using the dominant hand with the maximum force produced over five seconds; (ii) standing long jump (SLJ in cm) – assessed lower body explosive strength via maximum jumping distance recorded from two trials ; (iii) shuttle-run (SR in s) - from a starting line, children ran as fast as possible to a line nine meters away where two wooden blocks were placed, picked up one block at time and returned to the starting line and placed the block on the line. The shortest time of two trials was assessed by chronometry (Géonaute ON START 300) and used for analysis.

Birth weight (kg) was obtained retrospectively from children's health booklets. Height (cm) was measured, without shoes, using a portable stadiometer (Holtain, UK) holding the child´s head in the Frankfurt plane, (accuracy=0.1cm). Body mass (kg) was measured with a portable bioelectrical impedance scale (TANITA BC-418 MA Segmental Body Composition Analyzer; Tanita, Corporation, Japan) with children wearing light clothing and without shoes (precision=0.1kg). Body mass index (BMI) was calculated using the standard formula [BMI=body weight (kg)/height (m)^2].

The *KöperkoordinationsTest für Kinder* test battery [13] was used to assess GMC. The following were assessed: (i) walking backwards - children walked backwards on three different balance beams, decreasing in width, three times. The number of successful steps was counted; (ii) hopping - children hop, with one leg, over an increasing number of foam squares, according to their successful completion (three attempts are allowed at each height); (iii) jumping sideways - with feet together, children had to sideways jump as fast as possible over a wooden slat for 15s. This was repeated twice and the number of jumps (two trials) was summed; (iv) moving sideways - during 20s, using two wooden platforms, children stood with both feet on one platform and had to place both hands on an adjacent platform, thus passing to the next platform. The total number of relocations in two trials was recorded and summed. The sum of scores from these tests was used as a measure of total GMC (GMCS) [14]. Physical activity (PA) was objectively measured using an Actigraph GT3X+ accelerometer (Actigraph, Pensacola, USA) during 7 consecutive days (5 week-days and 2 week-end days). Children were instructed to only remove the device during water activities and while sleeping at night. The accelerometer was placed on the iliac crest and held in place by an elastic belt with an adjustable clip. Children's data were included based on a minimum of at least 4 days (with at least one weekend day) and a minimum of 10 hours of daily wear time. *ActiLife®* software 6.5.4 was used to process the recorded data. Moderate-to-vigorous PA (MVPA) was derived using cut-points developed by Evenson, Catellier, Gill, Ondrak, McMurray [15].

Families were divided into three SES levels using the school social support system developed by the Portuguese Ministry of Education de: (i) level A: up-to 2.934 €·year^{-1}, children received books and school lunches; (ii) level B: from 2.934 to 5.896 €·year^{-1}, with half of level-A support; (iii) level C: ≥5.897 €·year^{-1} implies no support [16].

All measures were taken by trained team members of the Kinanthropometry and Motor Learning Labs (Faculty of Sport, University of Porto). Each year a sample of ~60 children was randomly selected from each cohort and retested. Technical error of measurement (TEM) and ANOVA-based intraclass correlation (R) were used for reliability estimates: TEM=0.20cm in height, and 0.09kg in weight; R-values were ≤0.97 in PF tests, and ≤0.96 in GMC tests.

Descriptive statistics by sex across the years were calculated. Given the nested structure of the data (repeated observations nested within subjects nested within schools), a multilevel modeling approach was used [17]. As advocated [17], the time metric was centered at 5 years of age (time 0), such that 0, 1, 2, 3, 4, 5, and 6, corresponds to 5, 6, 7, 8, 9, 10 and 11 years of age. All analyses were performed in SuperMix v.1 software. Models were tested sequentially: the first described the best developmental trajectory for each PF test using age, age^2, sex, age-by-sex and age-by-sex^2 interactions as predictors; non-significant parameters were identified and dropped; in the second model cohort effects, non-varying (sex, birth weight and SES), and time-varying (BMI, GMCS, MVPA) covariates were added, and results for each of the three PF markers are presented. The significant level was set at 5%.

Results

Boys' and girls' descriptive statistics (mean ± SD or percentages) are shown in Table 2. As expected, PF, BMI and GMCS increased with increasing age. No differences were found between birth weights. Girls´ MVPA decreased until 9 yrs and increased thereafter; in boys this decrease was seen until 10 yrs and then increased. SES level C (≥5.870 €·year^{-1}) was the most frequent category noted.

In the first model (data not shown), no statistical significant effects were identified for the interactions of age-by-sex or age^2-by-sex, as well as for the school random effects, so these factors were not included in the final (second) model (Table 3). Regarding PF tests, means for a girl at 5 years of age were: HG = 7.74 kg, SLJ = 88.95 cm and SR = 15.49 s. Boys significantly outperformed girls at this age (+1.13 kg in HG, +7.88 cm in SLJ, and -0.33 s in SR) and this effect did not vary with age. The HG instantaneous velocity at 5 years was 1.43±0.19 kg and the average acceleration was also statistically significant (β=0.06±0.03, p<0.05). A similar trend was observed for SLJ (velocity, β=12.29±1.20, p<0.001; acceleration, 1.08±0.17, p<0.001), and SR (velocity, -0.93±0.09 s, p<0.001; acceleration, β=0.07±0.01, p<0.001). Cohort effects were all significant (p<0.05) in all PF markers. Birth weight was only significantly related to SR, i.e., children born with higher birth weight were, on average, more agile during childhood (β=-0.18±0.09, p<0.05). Further, SES was not significantly linked to any PF developmental trajectory. In contrast, children with higher BMI were stronger in HG (β=-0.35±0.04, p<0.001); less agile (β=0.06±0.01, p<0.001), i.e., need more time to do the test, and showed lower explosive strength (β=-0.93±0.23, p<0.001). Children with higher GMCS demonstrated better PF developmental trajectories (HG, β=0.02±0.00, p<0.001; SLJ, β=0.23±0.02, p<0.001; SR, β=-0.02±0.00, p<0.001). Additionally, more physically active children displayed a higher rate of increase in SLJ and SR, but not for HG development. Finally, children's PF developmental trajectories showed significant inter-individual differences, i.e., there was significant variation in the longitudinal age-related trends across individuals (HG, σ^2=0.21±0.10, p<0.05; SLJ, σ^2=9.39±3.42, p<0.05; SR, σ^2=0.06±0.02, p<0.001).

Table 2. Descriptive statistics (mean ± SD or percentage) for girls (n=177) and boys (n=171) from 5 to 11 years.

Tests	Girls						
	5 years (n=28)	6 years (n=58)	7 years (n=73)	8 years (n=73)	9 years (n=86)	10 years (n=47)	11 years (n=23)
Physical fitness							
Handgrip strength (kg^f)	6.2 ± 1.1	8.0 ± 2.0	10.0 ± 2.5	12.7 ± 3.1	14.1 ± 2.9	16.4 ± 3.3	19.4 ± 3.5
Standing long jump (cm)	76.3 ± 16.3	93.7 ± 17.3	102.7 ± 16.5	113.8 ± 16.9	120.9 ± 18.2	131.3 ± 18.3	135.1 ± 17.6
Shuttle run (sec)	16.6 ± 2.0	14.9 ± 1.5	14.0 ± 1.2	13.3 ± 1.1	12.9 ± 1.1	12.1 ± 1.0	11.8 ± 1.0
Gestational Information							
Birth weight (kg)	3.0 ± 0.6	3.0 ± 0.5	3.1 ± 0.5	3.2 ± 0.5	3.2 ± 0.5	3.2 ± 0.5	3.4 ± 0.4
Anthropometry							
BMI (kg·m^{-2})	16.7 ± 1.8	16.9 ± 2.0	17.7 ± 2.9	18.2 ± 3.2	19.0 ± 3.3	19.3 ± 3.4	20.2 ± 3.4
Gross Motor Coordination							
GMCS (points)	69.2 ± 22.5	103.0 ± 27.9	127.9 ± 28.8	155.8 ± 31.2	173.7 ± 32.4	207.1 ± 36.7	216.5 ± 42.7
Physical activity							
MVPA (min·d^{-1})	64.6 ± 21.1	61.6 ± 18.9	60.3 ± 18.1	58.9 ± 19.3	54.0 ± 15.8	58.2 ± 17.8	64.2 ± 32.2
Socioeconomic status							
A (up-to 2.934 €·year^{-1})	32.1%	15.5%	21.9%	20.5%	22.1%	21.3%	26.1%
B (2.934 to 5.896 €·year^{-1})	32.1%	36.2%	37.0%	26.0%	26.7%	21.3%	30.4%
C (≥5.870 €·year^{-1})	35.7%	48.3%	41.1%	53.4%	51.2%	57.4%	43.5%
	Boys						
	5 years (n=44)	6 years (n=62)	7 years (n=67)	8 years (n=60)	9 years (n=60)	10 years (n=39)	11 years (n=15)
Physical fitness							
Standing long jump (cm)	7.0 ± 2.3	9.1 ± 2.4	11.5 ± 2.5	13.8 ± 3.4	15.5 ± 3.5	17.8 ± 4.4	20.1 ± 4.4
Handgrip strength (kg^f)	85.6 ± 21.4	99.2 ± 19.2	114.7 ± 16.8	123.6 ± 18.6	130.4 ± 16.9	139.6 ± 15.3	143.5 ± 27.0
Shuttle run (sec)	15.8 ± 2.1	14.7 ± 1.7	13.4 ± 1.1	13.0 ± 1.1	12.4 ± 1.1	11.7 ± 0.7	11.6 ± 1.1
Gestational Information							
Birth weight (kg)	3.3 ± 0.6	3.4 ± 0.5	3.4 ± 0.5	3.3 ± 0.5	3.2 ± 0.5	3.3 ± 0.6	3.4 ± 0.5
Anthropometry							
BMI (kg·m^{-2})	17.0 ± 1.9	17.0 ± 2.1	17.2 ± 2.3	17.9 ± 3.7	18.5 ± 3.9	18.8 ± 4.3	19.0 ± 3.1
Gross Motor Coordination							
GMCS (points)	66.7 ± 27.0	103.1 ± 33.4	129.9 ± 37.1	156.0 ± 33.2	174.6 ± 38.2	201.5 ± 28.3	215.5 ± 44.4

Physical activity							
MVPA (min·d^{-1})	83.7 ± 23.5	82.6 ± 22.0	77.2 ± 24.1	74.8 ± 22.9	71.7 ± 20.8	68.5 ± 22.6	71.4 ± 19.8
Socioeconomic status							
A (up-to 2.934 €·year^{-1})	15.9%	14.5%	14.9%	11.7%	15.0%	7.7%	-
B (2.934 to 5.896 €·year^{-1})	18.2%	24.2%	23.9%	25.0%	23.3%	33.3%	46.7%
C (≥5.870 €·year^{-1})	65.9%	61.3%	61.2%	63.3%	61.7%	59.0%	53.3%

$PF_{ts\text{-}z}$= global Physical Fitness score; BMI= body mass index; GMCS = gross motor coordination score; MVPA= Moderate-to-vigorous physical activity.

Table 3. Parameter estimates (standard-errors) for fixed and random effects of the three multilevel models.

	Handgrip strength (kgf)	Standing long jump (cm)	Shuttle-run test (sec)
Regression coefficients (fixed effects)			
Intercept (5 years)	7.74 (0.43)***	88.95 (2.72)***	15.49 (0.19)***
Age (velocity)	1.43 (0.19)***	12.29 (1.20)***	-0.93 (0.09)***
Age^2 (acceleration)	0.06 (0.03)*	-1.08 (0.17)***	0.07 (0.01)***
Sex (boys)	1.13 (0.25)***	7.88 (1.48)***	-0.33 (0.09)***
CE_c2_1	-0.80 (0.32)*	-8.81 (2.38)***	0.18 (0.21)^{ns}
CE_c3_2	-0.87 (0.44)^{ns}	-12.48 (2.91)***	0.62 (0.24)**
CE_c4-3	-1.18 (0.49)*	-8.18 (2.90)**	0.68 (0.22)**
CE_c5_4	-1.25 (0.46)**	-5.27 (2.52)*	0.62 (0.18)***
CE_c6_5	-1.36 (0.35)***	-4.35 (1.73)*	0.50 (0.11)***
Birth weight (kg)	0.43 (0.23)^{ns}	0.25 (1.41)^{ns}	-0.18 (0.09)*
SES (level B)	-0.35 (0.35)^{ns}	-0.55 (2.13)^{ns}	-0.10 (0.13)^{ns}
SES (Level C)	-0.50 (0.32)^{ns}	-0.94 (1.93)^{ns}	0.02 (0.12)^{ns}
BMI ($kg \cdot m^{-2}$)	0.35 (0.04)***	-0.93 (0.23)***	0.06 (0.01)***
GMCS (points)	0.02 (0.003)***	0.23 (0.02)***	-0.02 (0.001)***
MVPA ($min \cdot day^{-1}$)	0.001 (0.003)^{ns}	0.08 (0.02)**	-0.003 (0.002)*
Variance components (random effects)			
Child Level			
Intercept	1.90 (0.58)**	217.67 (36.43)***	2.01 (0.27)***
Age	0.21 (0.10)*	9.36 (3.42)**	0.06 (0.02)***
Covariance (intercept/age)	0.09 (0.23)^{ns}	-33.36 (10.79)**	-0.34 (0.06)***
Residual Level			
Intercept	1.95 (0.16)***	74.79 (6.25)***	0.44 (0.03)***
Model Summary			
Number of estimated parameters	19	19	19

CE=cohort effects; CE_c2_1 is the overlapping effect of cohort 2 on cohort 1; SES= socioeconomic status; BMI= body mass index; GMCS = gross motor coordination score; MVPA= Moderate-to-vigorous physical activity; ns=non-statistically significant; * p<0.05; ** p<0.01; *** p<0.001.

Discussion

Static and explosive strength, as well as agility, exhibited non-linear developmental trajectories during childhood which were seemingly analogous to other non-statistically modelled longitudinal studies [18]. Neither SES nor the school environment explained differences in PF trajectories. Further, BMI, GMC and PA all affected children´s muscular strength and agility.

When controlling for covariates boys outperformed girls in all PF developmental trajectories. Such differences have been equated with biological and sociocultural aspects of sex [3]. For example, it has been suggested that parents are more prone to let boys be involved in more intense rough play whereas girls are treated as being more fragile [19]. Additionally, it has been suggested that boys choose activities that are more aligned with sex-specific roles [20]. Boys also tend to demonstrate higher motor performance [3] which is linked to neuromuscular mechanisms associated with PF development [21].

We did not find any relationship between children´s SES and their PF trajectories, which is in contrast to data from Bai, Saint-Maurice, Welk [11] who reported that school-children attending schools with higher SES showed better profiles in aerobic capacity and BMI. All children living in Vouzela, regardless of their SES inequality, have the same opportunities to develop their FMS into school, and consequently their PF, because all children have mandatory physical education classes and equal access to all facilities provided by the city hall.

BMI is known to rises differently as children age. This is the net expression of inter-individual differences in children's increases in height and weight which has been linked to motor performance and PF levels [9]. However, we showed that children's changes in static strength and agility were positively related to increases in their BMI, whereas SLJ was negatively associated. These results may be interpreted as follows: (1) with increasing age, children static strength increases and is related to neuromuscular development and increases in absolute muscle mass [3]; (2) agility development is linked to neuromuscular development, GMC and motor control, which all contribute to the effective acceleration and deceleration of the center of mass noted in repeated change of direction tasks better expressed in children with lower BMI values. And (3) although it has been suggested that vertical jumps are theoretically independent of body dimensions [22], and SLJ performance are proportional to height [23], empirical data contradicted these suggestions [22, 23]; in contrast, muscular strength production is proportional to cross-sectional to the power of 2, and body size is expected to be proportional to the power of 3, which means that greater body mass relative to height may impair the SLJ performance; thus, potentially explaining the negative relationship found between increases in BMI and decreased SLJ distance.

Physiological mechanisms including neuroendocrine and musculoskeletal maturation have previously linked birth weight with fat free mass and muscle fiber development [24], which aligns with the notion of a positive relationship between birth weight and physical performance [25]. However, in the present study we found no association of birth weight with static or explosive strength and a positive relationship with agility. Pikel, Starc, Strel, Kovač, Babnik, Golja [26] found that although low birth weight children underperformed in explosive leg strength and speed tests compared to normal birth weight peers, their agility tests were linked to GMC. Overall, the mechanisms of why specific longitudinal relationships are found, and not others, speaks to the importance of understanding both biological and experiential mechanisms for various aspects of physical development.

Children´s MVPA was not significantly associated with HG strength, but was positively interrelated to SLJ and SR performance. Although the longitudinal links between children PA and their PF trajectories are rarely investigated, especially with PA objective measurements, Augste, Lämmle, Künzell [27] showed that PA, measured by questionnaire, affected not only primary school-children composite PF z-scores baseline levels, but also their course. Further, Sallis, McKenzie, Alcaraz [28] showed that involvement in a multiplicity of physical activities consisting not only of physical education classes, but also sports, recreational activities and games are linked to improved PF levels. Children's participation in a variety of locomotor physical activities (as opposed to general strength-related activities), specifically in early childhood provides a logical link to tasks linked to lower extremities performance tests. Finally, we speculate that since HG is more specifically linked to static strength, whose values are highly dependent on body size, older and heavier children, and the specificity of the task, it may not be as strongly linked to children’s general PA levels.

It has been shown that children motor competence is positively related to PF levels. And that those with low or average rate of change in their motor competence developmental pathways are several times more susceptible to become overweight or obese by the end of primary school [29]. We found that more coordinated children across time are also those who display better PF developmental trajectories. Motor tasks of GMC and PF tests include movements with many degrees of freedom within the body, and the combination of muscle activity (isometric, concentric and eccentric) requires a high degree of inter- and intramuscular coordination and control [21]. Similarly, the structure of PF tasks are related to motor components/motor abilities inherent within GMC tasks.

We also found that Vouzela´s schools apparently do not significantly explain, above and beyond the significant physical development predictors, why children differ in their PF development. This may be due to the fact that there is no sufficient variation across schools in their infrastructures, settings, or curricula organization. For example, school-based *curriculum* in Portuguese primary schools is applied in the same manner with two times per week of physical education classes. Additionally, being predominantly rural, the Vouzela region has quite similar PA/sports facilities and graduate professionals conduct all Physical Education classes. Further, school effects remain non-significant even when cohort effects were modelled and tested [30], although it is possible that children´s lives and educational histories within each age-cohort could have impacted their PF developmental trends.

At least three limitations are acknowledged in this study: (1) the GMDC-Vouzela study does not cover all Portuguese regions, and care must be taken with generalizations based only on this sample; (2) although aerobic fitness and running speed were also collected, they were not used in this paper because there were too many missing data to validly include it in the analyses; (3) ideally, a pure longitudinal study covering annual, or semi-annual data collection, from 4 to 11 years would have provided a more robust longitudinal design. Yet, the comprehensive testing of multiple intraindividual and environmental factors linked to physical development has never been conducted and the mixed-longitudinal approach is a highly viable and reliable design.

Conclusion

Children´s PF development exhibited a non-linear trend with boys outperforming girls, even when considering significant cohort and other covariates´ effects. Schools and SES apparently had no additional explanatory power on children PF developmental trajectory differences. Overall, the complex nature of interactions among PF attributes, GMC and bodyweight status are difficult to untangle, specifically with the additional influence of biological growth and maturation variables. However, the unique nature of this investigation, with its comprehensive testing of potential correlates in multiple developmental domains, provides novel insight on the overall physical development of children.

Practical Implications

- PF has a curvilinear developmental trend. Further, with increasing age boys are, on average, more physically fit than girls.
- Development of muscular strength and agility are positively linked to BMI, GMC and PA.
- SES do not influence children PF development.
- The school context does not explain differences in children PF development.

Declaration of Interest Statement

No conflict of interest was reported by the authors.

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Artigo V

Biological, behavioral, and socioeconomic correlates of children changes in performance IQ

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ABSTRACT

The purposes of this study were to model children's intelligence, to investigate sex-differences and to identify the effects of fixed and dynamic correlates on intelligence development. A total of 69 Portuguese children (39 girls), from 6 to 8 years old, were followed consecutively for three years (2013-2014; 2014-2015; 2015-2016) using a mixed-longitudinal cohort design. Intelligence was obtained via WISC-III. Manual preference and socioeconomic status were identified. Gross motor coordination, body mass index and physical activity were assessed annually. A sequence of multilevel hierarchical linear models was developed. Model 1 included age, sex and sex-by-age where only age was significant (β=7.81±1.90, $p<0.05$). Model 2 found no significant differences in manual preference and socioeconomic status ($p>0.05$). Model 3 found that more coordinated children were more intelligent (β=-0.11±0.06, $p<0.05$). Body mass index and physical activity were not significant ($p>0.05$). In conclusion, children intelligence development was linear where boys and girls had similar trajectories. Manual preference, socioeconomic status, body mass index and moderate-to-vigorous physical activity had no effects on children´s intelligence development. From 6 to 8 years old, more coordinated children were more intelligent.

Keywords: Children; intelligence; longitudinal study; multilevel modelling analysis

Introduction

As children grow and develop, physically and cognitively, their intellectual abilities grow as well, with inter-individual differences in cognitive skills being widely expressed [1]. Further, childhood is an important time where an accelerated development in cognitive skills, namely intelligence coefficients (IQ), is expected to occur [2,3]. It has been suggested that there are no sex-differences in IQ performance during childhood, and that developmental differences probably start during adolescence and or late-adolescence [4].

Cross-sectional reports [5,6], and systematic reviews [7-9] have demonstrated consistency of putative predictors of children differences in their IQ development namely biological, behavioral and social factors [10,11]. For example, it has been suggested that obesity is negatively associated with IQ performance [12,13], and that children with higher levels of motor coordination, and greater physical activity express higher IQ levels [14 – 16]. Further, socioeconomic status (SES) and manual preference are also seen to play relevant roles in children´s ways of expressing their intelligence, where those from low-SES families showed greater variance in their IQ [17] and differences between right-handers and left-handers, although not expected, showed preferential IQ performance scores in left-handers [9].

Although there is a wealth of longitudinal information aiming to explore children´s intelligence development [1,4,18,19] ,we contend that a more comprehensive approach could include different domains of putative predictors. In the present study, the following aims were pursued: (1) to model children´s intra-individual and inter-individual differences in IQ performance, (2) identify possible sex-specific trajectories; (3) to examine the importance of manual preference and SES on IQ development, and (4) investigate effects of body mass index (BMI), gross motor coordination and physical activity (PA) on children IQ performance development.

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Materials and methods

Sample

Children were recruited from the Growth, Motor Development and Cognition Study, which was carried out in Vouzela city (GMDC-Vouzela Study), located in a central region of Portugal. Briefly, this research project used a mixed-longitudinal design, with six age-cohorts, using a Bronfenbrenner ecological systems theory [20] as its conceptual template. The study aimed to investigate the dynamic relationships between growth, motor performance, behaviour and cognition in children from 4 through to 11 years of age. Children were followed for three consecutive years (2013-2014; 2014-2015; 2015-2016) with a two-year overlap between cohorts [21]. In the present study only children from the third cohort (6 to 8 years of age) were considered, this age is an important window of children´s intellectual development – a transition from the preoperative to the concrete operations period [22]. In total 411 children were recruited. For the present study 69 children (39 girls and 30 boys) fulfilled the study eligibility requirements. Parents or legal guardians provided signed informed consent. The study was approved by the Ethics Committee of the Faculty of Sport, University of Porto, as well as by Vouzela´s educational, political and health authorities.

Intelligence

Intelligence was assessed using the Wechsler Intelligence Scale for Children - 3rd edition (WISC-III), which has been cross-culturally adapted to the Portuguese population by Simões et al. (2003) [23]. The WISC-III consists of thirteen subtests, six verbal and seven performance based (non-verbal) IQ scores. These results are interpreted according to the total IQ whose analysis allows determining the quality of a child's performance against a set of intellectual skills. For the present study only performance (non-verbal) subtests are used. The tests comprising five tasks, as previously suggested [24]: (i) picture completion: assesses visual alertness and visual long-term memory; (ii) coding: measure visual-motor dexterity, associative nonverbal learning and speed; (iii) picture arrangement: assesses visual comprehension, planning and social intelligence; (iv) block design: measure spatial analysis and nonverbal reasoning; (v) object assembly: assesses perception, assembly skills and flexibility. Scores from those tasks were summed to calculate the performance IQ (PIQ).

Each child assessment took 60 minutes plus ~30 minutes to compute her/his PIQ. Following Portuguese law, certified Psychologists performed the assessment, and given the shortage of such professionals in the region, available time, schools´ stringent schedules, and budget constraints we were only able to assess 69 children.

Anthropometry

Height was measured using a portable stadiometer (Holtain, UK), with children without shoes, and holding the child’s head, in the Frankfurt plane; the accuracy was 0.1 cm. Body mass (kg) was measured with a portable bioelectrical impedance scale (TANITA BC-418 MA Segmental Body Composition Analyzer; Tanita, Corporation, Japan) with children in light clothing; the precision is 0.1 kg. Body mass index was calculated using the classical formula: body mass (kg)/height $(m)^2$, and children were classified as normal weight (the reference category) and overweight or obese using the cut-points of the International Obesity Task Force [25].

Manual Preference

A short version of the Dutch Handedness Questionnaire 26 was used to assess manual preference, consisting of simple daily tasks where children self-report which hand they preferred to use (i.e., to pick up a pencil or hold a toothbrush). In young children, it is recommended to use the objects mentioned in the questionnaire to carry out the tasks (i.e, a bottle of water is placed in front of the child and he or she was asked to open it). For each task it was indicated whether the child used the right hand, the left hand or if there was no preference. Children were classified with left hand preference and right hand preference according to procedures outlined in the questionnaire. Left hand preference will be the reference category in our analyses.

Gross Motor Coordination

Gross motor coordination (GMC) was assessed using the *KöperkoordinationsTest für Kinder* battery (KTK) of tests [27] comprising four tests:

(1) walking backwards on balance beams (WB): children were asked to walk backwards three times on each of three (6 cm, 4.5 cm and 3 cm width) balance beams (3 m length, 5 cm height). The total successful steps (maximum 8) were computed; (2) hopping for height on one leg (HH): children hoped over a pile of pillows (60 cm x 20 cm x 5 cm each) without touching any, and continue hopping on the same foot at least 2 times to have a successful hop. The height was increased by adding one pillow at a time and the child had 3 attempts at each height and with each foot – the successful hop on the first trial corresponded to 3 points, on the second to 2 points and on the third trial to 1 point. Three trials for each leg at each height were recorded. A maximum of 78 points (39 for per leg) could be achieved; (3) jumping sideways (JS): children were asked to jump laterally and consecutively over a wooden slat (60 cm x 4 cm x 2 cm), with both fee together and simultaneously, as fast as possible for 15 seconds. The task was repeated twice and the number of jumps, over the two trials, was summed; (4) moving sideways (MS): children stood with both feet on a box (25 cm x 25 cm x 5.7 cm) and placed both hands on an adjacent box (25 cm x 25 cm x 5.7 cm). Then, they place the second box alongside the first and stepped on it, this movement was repeated over 20 seconds, as fast as possible, in two trials – the number of relocations were recorded (2 points). After the two trials the number of relocations was summed. The sum of scores from each test was used as a measure of total gross motor coordination (GMCS) as suggested by Schilling [28].

Physical Activity

Physical activity (PA) was assessed using Actigraph GT3X+ accelerometers (Actigraph, Pensacola, USA). Children were instructed to wear the device for seven consecutive days (5 week-days and 2 week-end days), and to only remove it during water activities and when sleeping. The accelerometer was placed on the iliac crest and was held in place by an elastic belt with adjustable clip. Upon retrieval of each accelerometer the *ActiLife®* software (version 6.5.4) was used to download data. To be considered valid children had to have at least 4 days (with at least one weekend day) of data, with a minimum of 10 hours of daily wear time. Non-wear time was considered any sequence of at least 20 consecutive minutes of zero activity counts [29]. Different expressions of PA were derived using cut-points developed by Evenson, Catellier, Gill, Ondrak, & McMurray (2008) [30]. For the present study, moderate-to-vigorous physical activity (MVPA) was used, defined as all activities greater than 574 counts/15 s epochs, and expressed in min·day^{-1}.

Socioeconomic status

We used the Portuguese school social support system to gather information about SES, which is based on an index budget reference of the Portuguese Ministry of Education directives[31]. Vouzela schools´ administration provided information regarding family levels based on this index: level A (up-to 2.934 €·year^{-1}), and children received books and feeding support (lunch at school); level B (from 2.934 to 5.896 €·year^{-1}) with half of level-A support; level C (≥5.897 €·year^{-1}) implies no support. A dummy code was created, with level A as the reference group.

Data quality control

A series of procedures were used for data quality control, namely for anthropometric measures, gross motor coordination, physical activity and hand preference (but see Reyes et al., 2018)[21], and all data showed to be highly reliable.

Statistical analysis

Descriptive statistics were performed in SPSS version 24.0 and included means, standard deviations and percentages, as appropriate. Since the data had a hierarchical structure, i.e., repeated observations nested within children, a multilevel model approach was used [32]. Further, we also relied on the Kenward and Roger (1997) [33] small-sample inference methodology as implemented in STATA 15 for the multilevel model [34]. We tested a sequence of models with increasing complexity as per our aims: Model 1 (M_1) only had 2 levels [repeated observations (level-1) nested within individuals (level-2)] and tested from developmental trends in children IQ as well as for sex-differences. In Model 2

(M_2) manual preference and SES, as fixed covariates, were added. Finally, in Model 3 (M_3) time-varying predictors like BMI, GMC and PA were added. All predictors were grand-mean centred as advocated [35], and the significance level was set at 5%.

Results

Table 1 provides descriptive statistics (mean ± SD or percentages) for girls and boys. As expected, boys´ and girls´ mean PIQ and GMCS increased with increasing age. There was a greater frequency of overweight and obese girls, ranging 31.6% to 48.8%, at 6 and 8 years´s olds. Right-handed children were more frequent (>89.5%). Boys spent more time in MVPA than girls; moreover a similar patterns occurred in both sexes - an apparent increase from 6 to 7 years of age and then a decrease from 7 to 8 years. Children with SES in level C (≥5.870 €·year^{-1}) were more prevalent.

The results of the multilevel models are shown in Table 2. In M_1, the average PIQ for a 6 year-old child was 97.39±2.29 points ($p<0.05$), and this increased by 7.81±1.90 points per year ($p<0.05$) thereafter. No significant sex differences in PIQ at 6 years of age was found (β=2.96±3.51, $p>0.05$), nor interaction between sex and age (β=0.29±2.29, $p>0.05$). Yet, there were inter-individual differences in children PIQ at 6 years ($\hat{\sigma}^2$=108.76±32.17, $p<0.05$), with variance increasing with increasing age ($\hat{\sigma}^2$=35.83±17.76, $p<0.05$). Model 2 (M_2) added manual preference and SES, but these were not statistically significant ($p>0.05$). In Model 3 (M_3), BMI, GMCS and MVPA were all added, however only GMCS showed significance (β=0.11±0.06, $p<0.05$), i.e., more coordinated children tend to have greater IQ performance scores. The inter-individual differences in children PIQ at 6 years ($\hat{\sigma}^2$=132.93±40.12, $p<0.05$) as well in their trends ($\hat{\sigma}^2$=32.77±24.76, $p<0.05$) remained.

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Table 1. Descriptive statistics (mean ± SD or percentage) for girls (n=39) and boys (n=30) across the study years.

	Girls			Boys		
Tests	6 years (n=31)	7 years (n=19)	8 years (n=20)	6 years (n=22)	7 years (n=17)	8 years (n=15)
Intelligence						
PIQ	96.9 ± 10.6	105.2 ± 15.3	114.4 ± 13.5	100.7 ± 13.8	120.3 ± 17.3	120.4 ± 26.1
Gross Motor Coordination						
GMCS (points)	106.2 ± 27.2	131.1 ± 35.9	149.9 ± 43.6	119.6 ± 24.0	145.9 ± 23.0	170.4 ± 36.0
Anthropometry						
Normal weight	51.6%	68.4%	60.0%	63.6%	64.7%	73.3%
Overweight and Obese	48.4%	31.6%	40.0%	36.4%	35.3%	26.7%
Manual Preference						
Right Handed	90.3%	89.5%	90%	95.5%	100%	93.3%
Left Handed	9.7%	10.5%	10%	4.5%	0%	6.7%
Physical activity						
MVPA (min·d^{-1})	60.2 ± 19.3	65.4 ± 17.3	62.6 ± 22.4	88.0 ± 26.5	90.7 ± 25.2	77.8 ± 24.1
Socioeconomic status						
A (up-to 2.934 €·year^{-1})	19.4%	10.5%	15.0%	9.1%	17.6%	13.3%
B (2.934 to 5.896 €·year^{-1})	38.7%	36.8%	35.0%	31.8%	35.3%	40.0%
C (≥5.870 €·year^{-1})	41.9%	52.6%	50.0%	59.1%	47.1%	46.7%

PIQ= performance intelligence quotient; GMCS = gross motor coordination score; MVPA= Moderate-to-vigorous physical activity.

Table 2. Parameter estimates (standard-errors) for fixed and random effects of the IQ multilevel models

	Model 1 (M_1)	Model 2 (M_2)	Model 3 (M_3)
Regression coefficients (fixed effects)			
Intercept (6 years)	97.39 (2.29)***	87.50 (8.19)***	94.93 (8.93)***
Age (velocity)	7.81 (1.90)***	7.44 (1.90)***	5.48 (2.32)***
Sex (boys)	2.96 (3.51)	1.31 (3.63)	3.40 (4.41)
Sex-by-age	0.29 (2.29)	1.05 (2.96)	0.63 (3.36)
Manual preference (right hand)		9.83 (7.16)	6.61 (7.61)
SES (level B)		-0.11 (4.90)	-2.79 (5.64)
SES (Level C)		3.05 (4.64)	-0.46 (5.14)
Body mass index (overweight and obese)			-0.88 (3.31)
GMCS			0.11 (0.06)*
MVPA ($min \cdot day^{-1}$)			-0.04 (0.07)
Variance components (random effects)			
Child Level			
Intercept	108.76 (32.17)*	106.41 (33.28)*	132.93 (40.12)*
Age	35.83 (17.76)*	33.19 (17.54)*	32.77 (24.76)*
Residual Level			
Intercept	69.54 (15.29)*	72.51 (16.19)*	48.55 (16.51)*
Model Summary			
-2LogLikelihood	-488.06	-471.74	-363.47
Number of estimated parameters	7	10	13

SES= socioeconomic status; GMCS= gross motor coordination score; MVPA= Moderate-to-vigorous physical activity; * $p<0.05$; ** $p<0.01$; *** $p<0.001$.

Discussion

The current study investigated children PIQ longitudinal trajectories as well as the effects of fixed and time-varying predictors. The main message is that the developmental narrative of PIQ did not change (from M_1 to M_3), showing that during this age range PIQ exhibited a linear trajectory which was apparently similar to other reports [5,36]. Further, neither sex, manual preference, SES, BMI and MVPA had any significant effect in explaining children differences in their PIQ. Yet, GMCS did.

Available results on sex-differences in intelligence are apparently inconsistent. Although it has systematically been suggested that no sex-differences are expected to occur in general intelligence [5, 37, 38], Sternberg [39] showed that there is some evidence of average patterns of intelligence differences between the sexes across time. Lynn [4,40] consistently reported no sex-differences in means of Full scale IQ (FSIQ) in children and youth aged 5 to 15 yrs; yet from 16 yrs onwards males tend to outperform females (on average, +4 points). In our study, we did not find any trend differences between boys and girls. In any case, we concurred with Deary [42] suggestion that future research on sex-differences in intelligence might consider general vs. specific cognitive abilities. The rationale is that boys and girls tend to show different performance levels in specific tests, namely in their ability to manipulate visual images in working memory - boys tend to show better results; on the contrary, in those tests demanding retrieval from long-term memory and verbal information (acquisition and use) girls are better performers [43].

It has been described that left-handedness has links with learning difficulties namely dyslexia [44] and some cognitive deficit [45]. However, in a recent systematic review and meta-analysis Ntolka and Papadatou-Pastou [8] reported no apparent link between handedness, although in 7 out of 20 reviewed papers some favored right-handers and other left-handers. In the present report we found no manual preference-differences associated with the PIQ and this may also be related to our small number of left-handers (n=5), i.e., 7.5% of the total sample although about ~10% of the population is expect to be left-hander [45]. As a final remark, we contend with Nicholls, Chapman, Loetscher, & Grimshaw [46] that eventual differential effects might be subtle and to clearly identify them large-scale studies are required, and that there might exist specific abilities in which right-handers have advantages comparatively to left-handers, and vice versa [46-48].

We were not able to identify any significant relationship between SES and children PIQ trajectories. Although available longitudinal children data on this issue is apparently scarce, it has been suggested that children from disavantage familial backgrounds tend to score lower in their IQ [6,17]. For example, Von Stumm and Plomin [6] showed that children from low SES levels tend to perform worse on intelligence tests than 2-year-old children from more privileged homes. Additionally, Hanscombe, et al. [17] studied twins and repported that parental SES affects moderate children IQ at ages from 2 to 14 years old. Although there is inequality in SES distribution in Vouzela city, all children, regardless of their SES, have the same opportunities to develop their intelligence in classrooms given the likeness of schools´ curricula. In addition, Vouzela has a well-equipped and structured public library, where all children, in addition to their school libraries, are systematically encouraged to visit and explore. Finally, Vouzela city-hall has frequent persuasive events to inspire children in reading practices.

Obesity has been connected with poor cognitive function and decrease in brain volume [49,50], and these could possibly induce lower IQ levels [13]. In a systematic review, Yu, et al.[13] reported that PIQ and FSIQ in obese school-aged children were lower than their normal weight peers. These results may be related to significant psycho-social-emotional impact that obesity has in children like low self-esteem and poor academic performance [52]. However, for Belsky et al. [53] this type of conclusion during the first half of the life course may be premature because the majority of available research are cross-sectional by design, and no temporal ordering of obesity and low IQ could be identified. Further, they followed a population-representative birth cohort of 1000 children during four decades and showed that IQ deficits in obese adults were already present during their childhood. In our study, changes in weight status were not associated with changes in PIQ. Vouzela´s overweight and obese children are systematically followed by health and educational professionals so that no side putative psychological effects like self-esteem would affect their academic performance, and thus their intelligence.

Both cross-sectional and longitudinal studies reported positive links between motor coordination and intelligence in typical developing children [54,55,56]. However, we were able to localize only one cross-sectional study that examined the associations between GMC, assessed with the KTK, and cognitive performance, including intelligence, in overweight and normal-weight children [57]. These authors showed that children with overweight were also those with low GMC performance as well as in intelligence when compared to healthy weight children even when controlling for the effects of social class and immigration status. Nevertheless, information about the relationship between intelligence and motor development (motor coordination, motor skills, etc.) can be found in the literature. For instance, van der Fels et al.[58] provided evidence of the relationship between motor and cognitive skills in typically developing children from 4 to 16 years of age. Further, Smits-Engelsman and Hill [59] investigated the relationship between motor coordination and IQ and the results showed that 19% of the variance in motor outcomes was explained by IQ scores. In our study, GMCS significantly linked with PIQ across 6 to 8 years old. This relationship can be explained, in part, by brain activation. Some of the neuroimaging brain regions previously thought to be totally related to motor activity (cerebellum and basal ganglia) and to cognition (prefrontal cortex), actually are co-activated during specific cognitive or motor activities [3]. In addition, simple natural effects can also explain it, that is, with increasing age, children are expected to develop both the motor and intellectual domains together [11].

Finally, the relationship between PIQ and GMCS mediated by PA may explain it. Available cross-sectional reports positively associated PA with cognitive skills and brain structure [59], academic achievement [60] as well as executive functions [61]. Further, a systematic review by Sibley and Etnier [62] revealed an overall effect size=0.32 between PA and improved cognition in children. In contrast, Wickel [63] examined longitudinal relationships between sedentary time, PA and executive functions (inhibition, working memory and fluid intelligence) in children at 9 and 15 yrs of age and concluded that sedentary time and PA may affect executive function at 15 yrs. Nevertheless, in our study, no longitudinal relationships between MVPA and PIQ were found. A possible explanation is that PA in early life optimizes brain networks involved in memory and creates a reserve of precursor cells that influence individuals´ learning abilities throughout the life span [64]. However, taking into account that the MVPA means did not change over time in our study, we speculate that this lack of change did not trigger a necessary neurological cascade.

This study is not without limitations. First, care must be taken when trying to generalize its results because the sample is not representative of the whole country. Second, the WISC-II was not used in its entirety and was not applied to all study cohorts, given shortage of specialized personnel. However, longitudinal studies in this age group and with more than two points in time are scarce and also has problems with the sample. For example, Taji, et al. [1] evaluated children from 5 to 7 yrs old and from 11 to 13 yrs old but they only used measures of intelligence of children aged 6 and 12 yrs old. This study also has several strengths: (1) the sample included children aged 6 to 8 yrs old which is considered an important developmental time window of intelligence; (2) the inclusion of a wide range of fixed and dynamic predictors allowing for a more encompassing way to understand spurts of IQ performance in children; and (3) the use of the multilevel model.

Conclusions

Children performance IQ increases in a linear fashion from 6 to 8 years´ olds, and no sex-differences were found. Further, no significant links were identified with performance IQ and manual preference or socioeconomic status, and the same occurred to body mass index and moderate-to-vigorous physical activity. Yet, more coordinated children tend to develop their IQ performance at a great rate.

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Declaration of Interest Statement

Any conflicts of interest were not reported by the authors.

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CAPÍTULO IV

CONCLUSÕES FINAIS

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O crescimento e o desenvolvimento de crianças ocorrem em tempo real em elevada inter-relação, governados pela complexa teia de fatores biológicos e contextuais. Ora o fluxo “acontecimental” desta tese procurou “retratar e filmar” algumas fatias desses processos. O seu curso, de caráter longitudinal-misto, funda-se no vasto território do Desenvolvimento Motor. Percorremos aspetos das caraterísticas individuais das crianças e dos seus estilos de vida que impactam as trajetórias do seu crescimento físico, desempenho motor e cognitivo. Essa “aventura” ocorreu no Concelho de Vouzela, região centro de Portugal.

O *GMDC – Vouzela Study* desenvolvido essencialmente no tempo do Programa Doutoral, é herdeiro de quase uma década de relações institucionais e académicas entre o Concelho de Vouzela e a Universidade do Porto. Servindo-se de uma perspetiva multivariada, em termos dos principais marcadores dos domínios do estudo, o estudo recorreu também às visões de reconhecidos desenvolvimentistas (Baltes & Nesselroade, 1979; Bronfenbrenner, 1977, 1979, 1996). Adicionalmente, o seu delineamento longitudinal-misto permitiu que num curto espaço de tempo fosse possível um olhar relativamente detalhado sobre a mudança intra-individual e as diferenças inter-individuais (Bell, 1954) de um conjunto variado de marcadores do crescimento e desempenho das crianças Vouzelenses.

Tal como referimos anteriormente, a presente tese é fruto de um extenso programa de pesquisa realizado na região de Vouzela (Ativo I, II e III) cujos propósitos, delineamentos, grandes linhas de atuação e produtos finais, sob forma de relatórios, foram apresentados no capítulo da metodologia geral. Os distintos trabalhos que constituem esta tese disponibilizam informação nova sobre o crescimento físico, coordenação motora grossa, aptidão física e desempenho cognitivo de crianças Vouzelenses. Os resultados obtidos são relevantes para diferentes atores nos domínios da Saúde e da Educação. Uma parte substancial será importante para decisores e gestores de políticas educativas, professores de Educação Física e pais das crianças.

Tal como foi previamente reportado, esta tese contém cinco artigos originais. Apresentamos de seguida, resumidamente, as principais conclusões de cada artigo, ligando-as, sempre que necessário, a questões e propósitos da pesquisa.

O **primeiro artigo** procurou responder às seguintes perguntas: Quais são as principais ideias, linhas de força e domínios de pesquisa do *GMDC – Vouzela Study?* Que resultados melhor descrevem as crianças no *baseline* temporal? Para tanto o artigo apresentou o delineamento geral e a metodologia do *GMDC – Vouzela Study*, bem como os resultados do *baseline* em meninos e meninas numa variedade de marcadores, mas não todos, do crescimento físico, do desempenho motor e cognitivo bem como das caraterísticas do estilo de vida das crianças.

O *GMDC – Vouzela Study* apresenta uma estrutura operativa de natureza multivariada, evidencia robustez, é isócrono e o seu impacto académico está alinhado com metodologias referenciadas na investigação internacional de relevo. Por exemplo, em três artigos metodológicos, com delineamento longitudinal, centrados na infância (Ahrens et al., 2011; Cairney et al., 2015; Golding, Pembrey, & Jones, 2001), nenhum aparenta ter a amplitude temática do *GMDC – Vouzela Study*. Não obstante as suas limitações, o *GMDC – Vouzela Study* possui um conjunto variado de caraterísticas e pontos fortes: (1) estar ancorado na teoria bio-ecológica de Desenvolvimento Humano de Bronfenbrenner (1977, 1979); (2) assentar num modelo estatístico complexo e flexível – a modelação hierárquica ou multinível (Hedeker and Gibbons, 2006); (3) possuir um vasto leque de variáveis ao nível das crianças e do contexto escolar; (4) debruçar-se sobre uma janela temporal decisiva em termos do desenvolvimento de crianças, i.e., dos 4 aos 11 anos de idade; (5) possuir um delineamento longitudinal-misto, combinando várias coortes com períodos de sobreposição; e (6) permitir uma recolha mais rápida e eficiente da informação.

Em termos gerais, os resultados referidos no *baseline* corroboram as tendências atuais à escala nacional e internacional, i.e, valores médios mais elevados dos meninos em termos de aptidão física e atividade física (Malina, 2014; Telford, Telford, Olive, Cochrane, & Davey, 2016). Por exemplo, Roriz De Oliveira et al. (2014) concluíram que meninos Portugueses são sistematicamente mais aptos fisicamente que as meninas num conjunto variado de testes (*handgrip, standing long jump, 50 yard dash, shuttle-run and 1-mile run/walk*), com exceção do *sit-and-reach*. Adicionalmente, Telford et al. (2016) reportaram que meninas Australianas são 19% menos ativas que os meninos, muito provavelmente por causa dos papéis sociais e culturais esperados para os meninos. As teias relacionais que se estabelecem entre os domínios no *baseline* podem induzir um impacto, positivo ou negativo, no desenvolvimento motor das crianças. Reforçam também a necessidade de pesquisas semelhantes ou eventualmente mais inovadoras que o *GMDC – Vouzela Study* de modo a identificar, com o maior rigor possível, crianças em risco no seu desenvolvimento motor, bem como momentos mais adequados para intervenções educativas mais eficientes.

Em síntese, os resultados e conclusões apresentados no primeiro artigo foram:

- O *GMDC – Vouzela Study* adotou uma abordagem multidisciplinar com um delineamento longitudinal-misto centrado numa gama informacional de natureza biológica, contextual e do estilo de vida que se associam intimamente aos processos de crescimento e desenvolvimento de crianças.
- Os resultados do primeiro ano mostraram que: (1) em média, as meninas têm maior quantidade de massa gorda; (2) os meninos são significativamente mais pesados no nascimento e possuem um comprimento cefálico maior que as meninas; (3) os meninos são mais coordenados, mais fisicamente aptos e mais ativos.
- Aproximadamente 60% das meninas não cumprem as recomendações diárias de atividade física moderada-a-vigorosa. Em contrapartida, a taxa de cumprimento dos meninos é de 74%.
- A maioria das escolas está localizada em áreas rurais; todas possuem *playgrounds* (com obstáculos); somente 5 escolas possuem um centro

desportivo, e todas as escolas possuem equipamentos para realizar atividades físicas/lúdicas de natureza variada.

O **segundo artigo** procurou responder às seguintes perguntas: Como se comportam as trajetórias de mudança de diferentes marcadores do crescimento físico de crianças Vouzelenses dos 4 aos 11 anos de idade? Quais são os efeitos de preditores fixos e dinâmicos nessas trajetórias? Haverá diferenças marcantes relativamente a referências internacionais? Para tanto, o artigo procurou: (1) modelar o crescimento físico (altura, o peso e o índice de massa corporal) das crianças; (2) investigar diferenças entre sexos; (3) inventariar os efeitos do estatuto socioeconómico, do peso e comprimento ao nascer, e de ganhos de peso e comprimento até aos 18 meses de idade e, (4) examinar as trajetórias da altura, do peso e do índice de massa corporal das crianças Vouzelenses relativamente às referências internacionais.

É por demais evidente que a análise da informação longitudinal é um desafio constante ao pesquisador que deseja interpretar, de forma mais minuciosa e esclarecida, a riqueza informacional contida nos dados acerca das mudanças no crescimento e desenvolvimento das crianças. Daqui que o uso da modelação hierárquica ou multinível seja pertinente quando se deseja descrever, interpretar e atribuir significado a essas mudanças (Twisk, 2013), para além de ser uma decisão consentânea com a literatura (Johnson, 2015; Pan & Goldstein, 1998).

Este artigo aponta que o peso e o comprimento ao nascer, bem como os ganhos do peso e comprimento até os 18 meses, têm efeitos positivos no crescimento físico (altura, peso e índice de massa corporal). Esses resultados estão em conformidade com a literatura disponível (Rogers et al., 2006; Wells, Hallal, Wright, Singhal, & Victora, 2005). Contudo, destaca-se a ausência de qualquer associação estatisticamente significativa do contexto escolar e do estatuto socioeconómico das famílias nas diferenças de crescimento físico entre as crianças. Numa comparação com dados internacionais (Kuczmarski, Ogden, Guo, & al., 2002), os valores médios do peso e do índice de massa corporal das crianças Vouzelenses encontram-se entre o percentil 75 e 90 relativamente à referência do CDC (mesmas referências utilizadas em Portugal). O impacto destes resultados, em termos institucionais, é por demais evidente, destacando o papel importante da vigilância pediátrica, das escolas e das famílias na educação para a saúde e hábitos nutricionais adequados das crianças.

Importa ressaltar que no plano institucional, o Concelho de Vouzela, dispõe de um grupo que supervisiona e disponibiliza orientação sobre práticas nutricionais e condições saudáveis para as crianças, pais/encarregados de educação. Por exemplo, uma equipa de saúde tem uma agenda educativa relativa à importância da alimentação saudável. Adicionalmente, e independentemente de desigualdades em termos de estatuto socioeconómico das crianças, há um conjunto variado de ações oferecidas pelas escolas e pela Câmara que abrange todas as crianças.

Em síntese, os resultados e conclusões apresentados no segundo artigo foram:

- As trajetórias de crescimento físico das crianças exibem uma tendência não linear, com exceção da altura.
- Crianças nascidas com maior comprimento e maiores ganhos no seu comprimento até os 18 meses tendem a ser mais altas; de modo semelhante, maior peso ao nascer e maiores ganhos ponderais aos 18 meses estão positivamente associados com maiores aumentos de peso durante a infância.
- Crianças com maior peso e comprimento ao nascer, bem como as que têm maiores ganhos de comprimento e ganho de peso aos 18 meses são as que apresentam, em média, maiores ganhos de índice de massa corporal entre 4 e 11 anos de idade.
- O contexto escolar não está significativamente associado às diferenças de crescimento das crianças Vouzelenses. O mesmo ocorre com o estatuto socioeconómico.
- Em média, os valores de peso e de índice de massa corporal das crianças Vouzelenses estão situados entre o percentil 75 e 90 comparativamente à referência internacional da CDC.

O **terceiro artigo** teve como propósitos: (1) modelar as mudanças intra-individuais da coordenação motora grossa de crianças e investigar se divergem nas suas trajetórias; (2) pesquisar possíveis diferenças entre sexos; (3) verificar se a preferência manual, o estatuto socioeconómico e/ou o peso ao nascer influenciam o desenvolvimento da coordenação motora grossa; e (4) indagar se a atividade física, aptidão física e índice de massa corporal influenciam o desenvolvimento da coordenação motora grossa das crianças.

O uso da modelação multinível e a estimação simultânea de todos os parâmetros de cada modelo permite leituras distintas do mesmo fenómeno quando se testam, sequencialmente, diferentes modelos de natureza mais expansiva, i.e., com maior número de parâmetros (maior complexidade). Neste artigo, e após ajustamento para o conjunto de preditores fixos e dinâmicos, observa-se uma narrativa distinta no desenvolvimento da coordenação motora grossa, i.e., as meninas são sistematicamente mais coordenadas. Nem sempre é claro na literatura a presença de um dimorfismo sexual com vantagem para os meninos (Barnett et al., 2016). Nesse particular, o presente artigo é, muito provavelmente, o primeiro a mostrar que a natureza do desenvolvimento da coordenação motora grossa é bem mais complexa do que mostra a simples análise do comportamento das médias em função da idade cronológica de meninos e meninas.

O artigo mostrou que crianças com maiores valores de índice de massa corporal tendem a ser menos coordenadas. É expectável, de certo modo, a influência negativa dos incrementos do índice de massa corporal na coordenação motora (D'Hondt et al., 2013; D'Hondt et al., 2014), sobretudo pela exigência da estrutura das tarefas motoras associadas a cada teste. Sobre o fato de os destros terem sido, em média, mais coordenados, o artigo mostra resultados alinhados com a literatura, ou seja, a existência de uma associação positiva entre a preferência manual e o desempenho coordenativo, favorecendo as crianças destrímanas. Não obstante a escassez informacional (Gabbard, Hart, & Gentry, 1995; Giagazoglou, Fotiadou, Angelopoulou, Tsikoulas, &Tsimaras, 2001), Porac and Coren (1981), tem sido sugerida a hipótese “do mundo baseado em destros” para explicar os resultados encontrados.

Adicionalmente, o artigo mostrou que crianças com maiores níveis de força muscular e agilidade tendem a ter um desenvolvimento coordenativo mais elevado. Parece ser consensual a associação positiva entre níveis de aptidão física e coordenação motora das crianças (Cattuzzo et al., 2016; Robinson et al., 2015), embora nem sempre seja fácil explicar a temporalidade causal nessa relação. Mas, o estatuto socioeconómico, o contexto escolar, o peso ao nascer e a atividade física moderada-a-vigorosa não influenciam significativamente o desenvolvimento coordenativo. Ademais, apontou que, quando controlado para o efeito dos preditores, as meninas tendem a ter um desenvolvimento coordenativo superior ao dos meninos.

Em síntese, os resultados e conclusões apresentados no terceiro artigo foram:

- A trajetória modal do desenvolvimento coordenativo é de natureza não linear.
- Crianças com maiores valores de índice de massa corporal tendem a ser menos coordenadas.
- Os destros são, em média, mais coordenados.
- Crianças com maiores níveis de força muscular e agilidade tendem a ter um desenvolvimento coordenativo mais elevado.
- O estatuto socioeconómico, o peso ao nascer e a atividade física moderada-a-vigorosa não influenciam significativamente o desenvolvimento coordenativo.
- Quando controlado para o efeito dos preditores, as meninas tendem a ter um desenvolvimento coordenativo superior ao dos meninos.
- O contexto escolar não está relacionado, significativamente, com o desenvolvimento coordenativo das crianças.

Os objetivos do **quarto artigo** foram os seguintes: (1) modelar as trajetórias intra-individuais do desenvolvimento da aptidão física e identificar a magnitude das diferenças inter-individuais; (2) pesquisar sobre os efeitos dos preditores fixos, como o sexo, o peso ao nascer e o estatuto socioeconómico, bem como (3) inventariar as influências de preditores dinâmicos, como a idade, índice de massa corporal, a coordenação motora grossa e a atividade física no desenvolvimento da aptidão física das crianças.

Parece ser inequívoco que com o aumento da idade aumentem os níveis (médios) de aptidão física das crianças (Malina, Bouchard, & Bar-Or, 2004), mesmo controlando para o efeito de um conjunto variado de preditores. Um dos preditores mais relevantes é o aumento do tamanho do corpo, expresso em termos absolutos, a que se associam os incrementos de massa muscular e melhoria da expressão neuromuscular.

Os níveis mais elevados de atividade física moderada-a-vigorosa associaram-se positivamente com o desenvolvimento da força explosiva e agilidade, possivelmente devido ao fato da participação sistemática das crianças em gamas variáveis das suas atividades diárias. Ficou também evidente que as crianças mais coordenadas são fisicamente mais aptas. Tal como referimos anteriormente, não é fácil deslindar a complexidade do novelo relacional entre coordenação motora, aptidão física e atividade física, sobretudo no domínio da sua temporalidade causal. Num outro plano, este novelo com um dinamismo temporal próprio revela o carácter multivariado e inter-relacional do desenvolvimento motor das crianças.

Em ambos os artigos (III e IV), os níveis distintos do estatuto socioecónomico não se associaram significativamente com as trajetórias do desempenho coordenativo e da aptidão física das crianças Vouzelenses ao longo dos anos, não obstante a sugestão para ume eventual ligação (Bai, Saint-Maurice, & Welk, 2017; Vandendriessche et al., 2012). Embora a desigualdade social esteja presente no Concelho de Vouzela, todas as crianças, independentemente do seu estatuto socioeconómico, têm as mesmas oportunidades para elevar os seus níveis de proficiência nas habilidades motoras e, consequentemente, na coordenação motora grossa e aptidão física. A Educação Física está implementada em todas as escolas, há programas sistemáticos de iniciação pré-desportiva da Autarquia para todas as crianças, bem como é facilitado o acesso às infraestruturas desportivas da região.

Uma constante nesta tese é a sugestão da não associação significativa do contexto escolar com variadas expressões do desempenho motor e crescimento físico das crianças. Contudo, tal resultado não significa a não relevância do contexto escolar. Bem pelo contrário! Do ponto de vista educacional este não-resultado é extremamente favorável ao Concelho de Vouzela, uma vez que tem sido disponibilizado a todas as escolas inúmeros incentivos de natureza educativa, equipamentos e alterações infra-estruturais (na medida do possível) de forma a proporcionar a todas as crianças as condições mais adequadas ao seu desenvolvimento motor e cognitivo. Além disso, todos profissionais que lecionam nas escolas do Concelho de Vouzela são graduados. Adicionalmente, o Concelho possui um Gabinete de Desporto sistematicamente ativo na proposta e implementação de programas dirigidos às crianças e suas famílias ao longo de todo o ano.

Em síntese, os resultados e conclusões apresentados no quarto artigo foram:

- O desenvolvimento da aptidão física das crianças mostra uma tendência não linear, e os meninos são sistematicamente mais aptos.
- Crianças nascidas com maior peso ao nascer são mais fortes e mais ágeis. Em contrapartida, as que têm tendência para valores mais elevados de índice de massa corporal são menos ágeis, mas mais fortes.
- Crianças mais coordenadas são também mais aptas fisicamente. Similarmente, quanto maior for o nível de atividade física das crianças tanto maior é o desenvolvimento da sua força explosiva e agilidade.
- O estatuto socioeconómico não está significativamente relacionado com as diferenças de aptidão físicas das crianças.
- O contexto escolar não se associou significativamente com o desenvolvimento da aptidão física das crianças.

Os objetivos do **quinto artigo** foram os seguintes: (1) modelar a mudança intra-individual e as diferenças inter-individuais das crianças em seus níveis de desempenho do seu QI; (2) investigar possíveis diferenças entre meninos e meninas, e (3) sobre os efeitos do estatuto socioeconómico e da preferência manual; (4) mapear os efeitos do índice de massa corporal, da coordenação motora grossa e da atividade física nas trajetórias de desempenho do QI.

O artigo mostrou que o desenvolvimento da inteligência das crianças é linear dos 6 aos 8 anos de idade, sem diferença entre os sexos. Neste artigo, de todos os preditores utilizados para interpretar as diferenças nas trajetórias da inteligência das crianças Vouzelenses dos 6 aos 8 de idade, apenas a coordenação motora grossa mostrou uma relação positiva e significativa. Não obstante a existência de pesquisa relacional entre manifestações distintas da inteligência e o desempenho motor (Smits-Engelsman & Hill, 2012; van der Fels et al., 2015), localizamos somente um estudo com delineamento transversal que fez esta ligação com a coordenação motora (Krombholz, 2013) mas em crianças com sobrepeso e obesidade.

A relação que encontramos no nosso artigo era expectável, uma vez que se espera que com o aumento da idade as crianças o desenvolvimento da criança seja multifacetado, abrangendo os domínios motor e cognitivo (Papalia et al., 2006). A associação significativa encontrada tem sido explicada, em parte, pela ativação cerebral em que neuro-imagens de regiões cerebrais que se pensava estarem relacionadas exclusivamente com a atividade motora (cerebelo e gânglios da base) e a cognição (córtex pré-frontal) sejam co-ativadas, de modo interativo, durante as mais diversas atividades cognitivas e motoras (Diamond, 2000)

Ademais, o artigo mostrou que a preferência manual, o estatuto socioeconómico, o índice de massa corporal e a atividade física moderada-a-vigorosa não se associam significativamente com o desenvolvimento da inteligência. Destaca-se, mais uma vez, que o estatuto socioeconómico das crianças Vouzelenes não explicaram as diferenças nas trajetórias de mudança da inteligência (tal como ocorreu nos estudos sobre o crescimento físico, coordenação motora grossa e aptidão física). Este resultado é extremamente positivo do ponto de vista educacional.

Em síntese, os resultados e conclusões apresentados no quinto artigo foram:

- A tendência de desenvolvimento da inteligência das crianças é linear dos 6 aos 8 anos de idade.
- Meninas e meninos têm trajetórias semelhantes no desenvolvimento da inteligência.
- A preferência manual, o estatuto socioeconómico, o índice de massa corporal e a atividade física moderada-a-vigorosa não se associam significativamente com o desenvolvimento da inteligência.
- Os níveis de coordenação motora tendem a associar-se positivamente com o desenvolvimento da inteligência.

LIMITAÇÕES DA TESE

Não obstante o modo como a presente tese foi pensada, o método utilizado, os resultados obtidos e o seu alcance em termos científicos e educacionais, convém salientar que não está isento de limitações. Os pontos seguintes referem-se, exclusivamente, ao domínio metodológico.

1. Não obstante o reconhecido valor e potencialidade do delineamento longitudinal-misto, se tivéssemos a possibilidade de realizar um estudo com delineamento longitudinal puro dos 4 aos 11 anos, i.e., durante 7 anos consecutivos, teríamos um manancial informativo de inegável valor para investigar, por exemplo, a ocorrência do salto pré-pubertário e alinhar o desempenho das crianças pelo momento em que ocorre no mesmo sentido com que se alinha o desempenho motor de adolescentes pela idade em que ocorre o pico de velocidade da altura. Contudo, teríamos que enfrentar problemas complexos de natureza logística e financeira que na maior parte dos casos são insanáveis

2. Se porventura pudéssemos adicionar pelo menos mais um ano de recolha em cada coorte estaríamos na posse de maior preciosidade informativa para obter uma compreensão mais vasta da mudança intra-individual e das diferenças inter-individuais no seio de cada coorte, i.e., do *tracking* de variados aspetos do seu desenvolvimento motor.
3. Se porventura a dimensão amostral no seio de cada coorte fosse mais elevada teríamos menos *chances* de ocorrência de *drop-outs*, i.e., de crianças que abandonem o estudo, bem como na redução no número de casos com informação omissa. Contudo, convém salientar, que procuramos envolver praticamente todas as crianças do pré-escolar e do 1º Ciclo do Ensino Básico.
4. A recolha de informação foi feita nas 19 escolas dos dois agrupamentos escolares do Concelho de Vouzela. Não há mais! Claro que este fato pode colocar alguma dificuldade no processo de estimação dos parâmetros do terceiro nível (i.e., das escolas) uma vez que só temos 19. Este é, sem dúvida um problema. Contudo, convém realçar que entre as sugestões dos estudos de simulação realizados no computador e a metodologia pensada e implementada em cada estudo há sempre uma distância considerável – a da realidade concreta das condições da sua realização.
5. A avaliação da coordenação motora grossa foi efetuada com a bateria de testes KTK. Não obstante a latitude da sua utilização em estudos realizados em Portugal, no Brasil, na Alemanha, Holanda e Bélgica, temos bem presente as limitações inerentes à estrutura das tarefas dos quatro testes em termos de generalização da noção de coordenação motora grossa.
6. Não foi colhida informação sobre o nível de proficiência e desenvolvimento das habilidades motoras fundamentais das crianças, bem como sobre a competência motora percebida. Esta é, sem dúvida, uma limitação. Contudo, restrições de vária ordem não

permitiram que tal fosse possível, para além da complexidade da tarefa associada à colheita de tal informação nas crianças de todas as coortes.

7. Questões de natureza operativa e de falta de recursos de vária ordem não permitiram que fosse obtida informação sobre as rotinas de vida diária das crianças com base em observação direta. Estamos convitos que este tipo de informação seria de grande valia na largura da interpretação de aspetos do desenvolvimento motor das crianças.
8. Finalmente, não nos foi possível obter uma medida suficientemente capaz de informar com a maior extensão sobre o desenvolvimento cognitivo das crianças. A nossa opção foi "ambiciosa" – inteligência, desempenho escolar e compreensão leitora. Por questões de natureza operacional e de recursos, limitamos o nosso estudo à inteligência, mormente uma das suas expressões marcadas pela bateria de testes WISC-III. Ademais, o tempo disponível para levar a bom porto esta tese não permitiu que nos debruçássemos sobre a compreensão leitora e o desempenho escolar.

DESAFIOS FUTUROS

Face ao "terreno lavrado" na presente tese, o alcance das limitações anteriormente referidas, o conhecimento que temos neste momento da literatura e de alguns dos desafios colocados ao próprio Desenvolvimento Motor, estabelecemos um brevíssimo conjunto de questões que gostaríamos de responder num futuro próximo. Claro que esta viagem nunca será realizada sozinha.

As questões foram formuladas em dois planos aparentemente "estanques" porque não nos foi possível dar-lhes um tratamento individual nesta tese. Há ainda um outro conjunto de questões, mais complexo, que exige um maior cuidado em termos de formulação futura. Antecipo-o, mas não verti aqui.

1. Crescimento Físico:
    - Haverá estabilidade em distintos indicadores do crescimento físico ao longo da infância?
    - Que tipos de influência exercem os diferentes marcadores da gestação no crescimento das crianças?
    - Qual é a dinâmica da mudança em crianças com sobrepeso e obesidade no início do estudo? Quais são os preditores que melhor explicam esta mudança?
    - Há, ou não, estabilidade em grupos de risco ponderal ao longo dos anos de estudo?

2. Desempenho Motor:
    - Qual é o *tracking* das diferentes componentes individuais do desempenho motor e da coordenação motora grossa?
    - Qual é a dimensão da influência de preditores fixos e dinâmicos no *tracking* da coordenação motora grossa? E em cada uma das componentes individuais do desempenho motor?
    - Qual é a extensão da dinâmica relacional quando se estuda, em simultâneo, o desenvolvimento coordenativo e desempenho motor? Qual é a magnitude da influência de preditores fixos e dinâmicos?
    - Será possível identificar grupos de crianças “em risco” no seu desenvolvimento coordenativo? Qual é o perfil multidimensional destas crianças?

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